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HOW TO STAY SHARP INTO OLD AGE

EXERCISES THAT BOOST BRAINPOWER

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SCIENTIFIC AMERICAN MIND Volume 23, Number 4, Winter 2015

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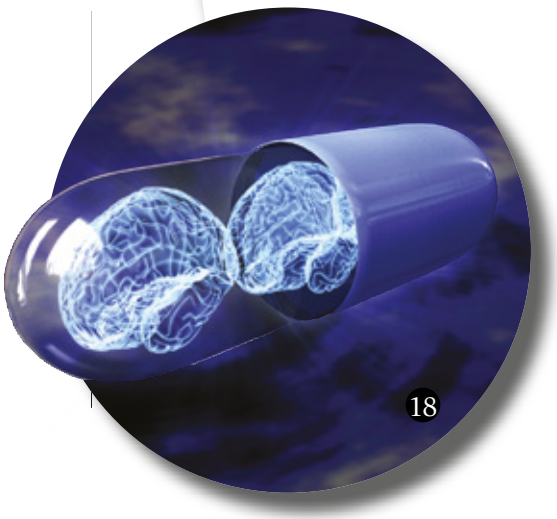

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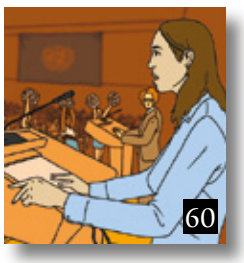

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GET SMART

Experts have identified many strategies for cultivating brilliance

To join the Mega Society, you have to score at the one-in-a-million level on an intelligence test. The group has only 27 members. Even those people, though, rarely claim to be geniuses. So what does it take?

As Dean Keith Simonton explains in "The Science of Genius," beginning on page 4, IQ is not the only, or even best, measure of genius. Creative output is perhaps a better gauge. Even with an abundance of raw talent, it still takes years of work to achieve greatness.

Practice makes perfect, but it is a mistake to spend all your time working or studying. Albert Einstein, for example, got lots of sleep, played the violin regularly and had other interests besides physics. In "Fit Body, Fit Mind?" (page 32), Christopher Hertzog and his colleagues show that physical activity is strongly linked to mental acuity and can help slow the cognitive decline that comes naturally with aging. In "The Aha! Moment" (page 48), Nessa Bryce lays out concrete steps for making inspired mental leaps.

Parents and teachers want to unleash brilliance in children as well as themselves. In "Nurturing the Young Genius" (page 60), education experts emphasize the value of giving children opportunities to flex their intellects. In "What Works, What Doesn't" (page 40), psychology professors describe study techniques that accelerate learning—and reveal that the most popular methods are, in fact, a waste of time.

The good news is that intellectual abilities are not set in stone. That realization may someday lead to brain-training exercises, such as the ones reported by Ingrid Wickelgren in "Calisthenics for a Child's Mind" (page 84), becoming routine in classrooms. Researchers are already teaching some kids that "the brain is like a muscle that gets stronger with use," writes Carol S. Dweck in "The Secret to Raising Smart Kids" (page 76). She advocates a "growth mind-set" that focuses on effort and effective strategies rather than innate intelligence.

Approaching life—including the mistakes we all make along the way—as an opportunity for learning can make everyone more successful in school, business and even relationships.

Dawn Stover
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THE SCIENCE OF GENIUS

OUTSTANDING CREATIVITY IN ALL DOMAINS MAY STEM FROM SHARED ATTRIBUTES AND A COMMON PROCESS OF DISCOVERY

BY DEAN KEITH SIMONTON

ILLUSTRATION BY NOMA BAR

Identifying genius is a dicey venture. Consider, for example, this ranking of "The Top 10 Geniuses" I stumbled across on Listverse.com a few years ago. From first to last place, here are the honorees: Johann Wolfgang von Goethe, Leonardo da Vinci, Emanuel Swedenborg, Gottfried Wilhelm Leibniz, John Stuart Mill, Blaise Pascal, Ludwig Wittgenstein, Bobby Fischer, Galileo Galilei and Madame de Staël.

What about Albert Einstein instead of Swedenborg? Some of the living might also deserve this appellation—Stephen Hawking comes to mind. Another female genius or two might make the cut, perhaps Marie Curie or Toni Morrison. And if a chess champion, Fischer, is deemed worthy, other geniuses outside the arts and sciences ought to deserve consideration—Napoleon Bonaparte as a military genius, Nelson Mandela as a political genius or Bill Gates as an entrepreneurial genius, to name a few candidates.

All these questions and their potential answers can make for some lively cocktail party conversations. What they reveal is how little we understand about the origins of intellectual and creative eminence. Explorations of this age-old debate have long sought to tease out the common features of geniuses working in disparate domains. The existence of unifying threads—including genetic factors, unusually broad interests and a link with psychopathology—suggests that the mind of a genius has a discernible shape and disposition.

Ultimately the goal is to explain how an eminent thinker arrives at his or her world-changing moment, or moments, of insight. Although such breakthroughs often seem to appear in a flash, the underlying mechanisms are likely to be much more orderly. According to one theory I helped to develop, a genius hunts widely—almost blindly—for a solution to a problem, exploring dead ends and backtracking repeatedly before arriving at the ideal answer. If this line of research bears out, we can start to investigate whether genius can be cultivated, unleashing a wealth of new ideas for the benefit of all.

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Psychologists often assess geniuses by their achievements, such as painting the Sistine Chapel, rather than by IQ scores.

FAST FACTS

GENIUS, DEFINED

1. Genius has been viewed two different ways: as achieved eminence and as exceptional intelligence. The former metric offers the more useful definition.
2. Genetics and life experiences both contribute to genius. Creative contributions can occur only after a domain has been mastered, but genetics can help a person improve faster and accomplish more with a given amount of expertise.
3. Genius can share certain potentially negative traits with mental illness, but when these traits are combined with specific positive attributes, the result is creativity rather than psychopathology.
4. A scientific genius has different expertise than an artistic genius, but all creative geniuses may depend on the same general process: blind variation and selective retention.

The Meaning of Genius

The first hurdle in the study of genius is to settle on a working definition. The word itself harks back to ancient Roman mythology, according to which every male was born with a unique genius that served as a kind of guardian angel, and every female had a juno. Much later, after the Renaissance, the word became more exclusive in its application, with only a few people showing genius. Philosopher Immanuel Kant believed, for example, that a genius was someone who produced works that were both original and exemplary. The term did not acquire scientific meaning until the late 19th century, when psychologists came to define genius in two distinct ways.

The first approach was to identify genius with exceptional achievement, as Kant did. These accomplishments elicit admiration and emulation from other experts in that field and often the world at large. Unquestioned examples of such works include Newton's *Principia*, Shakespeare's *Hamlet*, Tolstoy's *War and Peace*, Michelangelo's Sistine Chapel frescoes and Beethoven's Fifth Symphony. Even though this definition can be extended to encompass extraordinary leadership, such as military brilliance, and prodigious performance, including some chess grandmasters, most scientific research concentrates on outstanding creativity within the sciences or the arts, which will also be the focus here.

The second definition of genius coincided with the emergence of intelligence tests in the first half of the 20th century. A genius was someone who scored sufficiently high on a standard IQ test—usually landing in the top 1 percent, with a score above 140, as proposed by psychologist Lewis Terman, the formulator of one of the original intelligence tests. These two definitions have little in common. Many persons with superlative IQs do not produce original and exemplary accomplishments. One example is Marilyn vos Savant, who was once certified

FRANK HEUER *Redux Pictures*

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by the *Guinness Book of World Records* as having the highest recorded IQ of any living person. Her weekly Ask Marilyn column for a Sunday newspaper supplement did not inspire a new genre of science, art or even journalism. And many exceptional achievers do not attain genius-level IQs. William Shockley, for example, received a Nobel Prize in Physics for coinventing the transistor yet had an IQ score well below 140. Exceptional achievement, then, seems the more useful measure.

GENIUSES ARE LIKELY TO EXHIBIT UNUSUALLY WIDE INTERESTS AND HOBBIES, OFTEN CONTRIBUTING TO MORE THAN ONE DOMAIN OF EXPERTISE.

Too often in popular writing, genius is conceived as a discrete category—this person is a genius, but that person is not. Yet just as people can vary in IQ, they can also differ in the magnitude of their creative achievements, with either a single notable contribution or a lifetime of prolific work. One such "one-hit wonder" is Gregor Mendel, who attained lasting fame for a single paper that reported his classic experiments in genetics. Had Mendel never taken an interest in breeding peas, his name would be unknown today. Charles Darwin's fame, in contrast, rests on far more than *On the Origin of Species*. Nobel laureate Max Born once said that Einstein "would be one of the greatest theoretical physicists of all time even if he had not written a single line on relativity." Hence, Darwin and Einstein exhibited greater genius than did Mendel. Accordingly, much research is devoted to assessing relative degrees of genius—most often gauged by creative productivity.

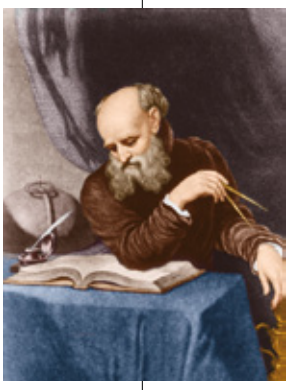
Origins of Genius

Finding the sources of consummate creativity has occupied the minds of philosophers and scientists for centuries. In 1693 English poet John Dryden wrote, "Genius must be born, and never can be taught." Two and a half centuries later French author Simone de Beauvoir countered, "One is not born a genius, one becomes a genius." The first scientific investigation devoted exclusively to genius concerned this precise issue. In 1869 Francis Galton published *Hereditary Genius,* in which he argued that genius is innate, based on his observations that geniuses tend to emerge from lineages that included other brilliant individuals. In response to criticisms, Galton later introduced the well-known nature-nurture issue. He conducted a survey of famous English scientists to discover some of the environmental variables involved in nurturing brilliance, and he examined factors such as birth order and education.

By the second half of the 20th century psychologists had moved to an extreme nurture position, in which creative genius rested solely on the acquisition of domain expertise. This idea was frequently expressed as the "10-year rule." Nobody can expect to reach the heights of creativity without mastering the necessary knowledge and skill because only experts can create—or so the thinking went. Indeed, Einstein learned lots of physics before he commenced his creative career.

This explanation cannot account for all the details, however. First, geniuses often spend less time acquiring domain expertise than their less creative colleagues. Studies have linked accelerated acquisition with long, prolific and high-impact careers. The 10-year rule is an average with tremendous variation around the mean. Further, major breakthroughs often occur in areas where the genius must create the necessary expertise from scratch. Telescopic astronomy did not exist until Galileo pointed his new instrument toward the night sky to discover what had never been seen before nor even expected. The moon had mountains, Jupiter had moons and the sun had spots!

Second, geniuses are more likely to exhibit unusually wide interests and hobbies and to display exceptional versatility, often contributing to more than one domain of expertise. This tendency not only was true in the era of Renaissance men but also is evident today. According to a 2008 study, Nobel laureates in science are more involved in the arts than less eminent scientists. Given that geniuses might not sleep any less than the rest of us, these extraneous activities would seem to distract from a dogged focus on a narrow field of interest. Einstein slept even more hours than the norm, but he still took time off to play Bach, Mozart and Schubert on his violin. At times these avocational activities inspire major insights. Galileo was probably able to identify the lunar mountains because of his training in the visual arts, particularly in the use of chiaroscuro to depict light and shadow.



To build the two-lens telescope he used to survey the skies, Galileo had to first learn how to grind his own lenses and discover the optimal lens combination.

The expertise acquisition theory also undervalues the genetic components that

THE AUTHOR

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MEASURING GENIUS

In 1926 Catharine Cox estimated the IQs of 301 eminent individuals. Using biographical data on early intellectual development, she and her collaborators calculated IQ using the formula IQ = 100 × MA/CA, where MA = mental age and CA = chronological age. Some representative results are shown here. (The actual scores are taken from a secondary analysis of her data that I published with Anna V. Song of the University of California, Merced.) These rankings illustrate the value of using achieved eminence, rather than intelligence test scores, as a measure of genius. Philosopher George Berkeley, for example, did not leave a greater mark on the world than Newton or Leonardo. Further, eight of these creative geniuses have IQs below the "genius threshold" of 140. —*D.K.S.*

IQs	Scientists	Philosophers	Writers	Artists	Composers
190s		Gottfried Wilhelm Leibniz	Johann Wolfgang von Goethe		
180s	Blaise Pascal	John Stuart Mill	Voltaire		
170s	Pierre-Simon Laplace	George Berkeley	Samuel Taylor Coleridge		
160s	Isaac Newton	René Descartes	Charles Dickens	Michelangelo	
150s	Johannes Kepler	Baruch Spinoza	Michel de Montaigne	Leonardo da Vinci	Wolfgang Amadeus Mozart
140s	Charles Darwin	Emanuel Swedenborg	Molière	Peter Paul Rubens	Ludwig van Beethoven
130s	Nicolaus Copernicus	Jean-Jacques Rousseau	Robert Burns	Rembrandt van Rijn	Gioachino Rossini
120s			Miguel de Cervantes	Bartolomé Esteban Murillo	Cristoph Willibald Gluck

underlie a large number of cognitive abilities and personality traits that correlate with genius. In a recent meta-analysis, I found that at least 20 percent of the variation in creativity could be attributed to nature. For example, creative achievement is strongly associated with the personality trait of openness to experience, a highly heritable characteristic. The broad interests in art and music of many geniuses are clear manifestations of this trait. Many other predictors of achievement also have high heritabilities, such as cognitive and behavioral flexibility, along with a tolerance of ambiguity and change.

Nurture may still account for the lion's share of genius, and mastering a domain remains central. At the same time, genetics contributes heavily to the rate at which someone acquires the necessary skills and knowledge. Those with more innate talent can improve faster, launch their careers earlier and be more productive. In addition, genetics may help explain the different trajectories of equally well-trained individuals. Einstein did not know as much physics as many of his contemporary theoretical physicists, but what he did know went a long way. He could honestly say, "Imagination is more important than knowledge."

These influences are just a few of the ways genetics shapes the potential for genius. Let it suffice to note that I have probably understated the impact of genes on genius.

Madness and Magnificence

Researchers have long been tantalized by the question of whether the biological endowment of a genius also confers great setbacks. Greek philosopher Aristotle is reputed to have said, "Those who have become eminent in philosophy, politics, poetry and the arts have all

ISTOCKPHOTO

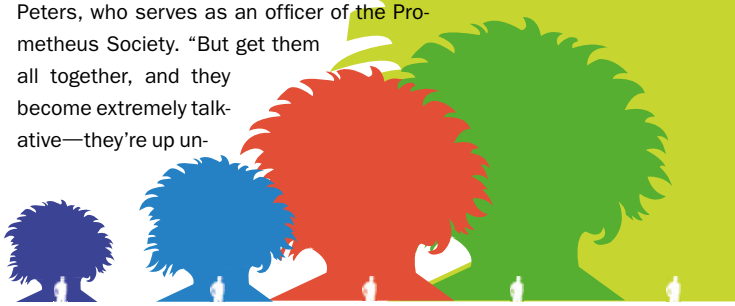
WHEN HIGH IQS HANG OUT

"Genius" societies offer a social network for the top tier of test takers ***By Lena Groeger***

Kevin Langdon was writing several books and designing an inside-out clock. Karyn Huntting Peters was organizing a global problem-solving network. Alfred Simpson juggled multiple Web-programming projects in his free time. These three people might not have had much in common—except for their unusually high IQs.

All three belong to exclusive high-IQ societies. Mensa International, whose members' test scores must land above the 98th percentile (or one in 50), may be the most popular, but it is just one option for the discerning test taker. The Triple Nine Society demands an IQ in the 99.9th percentile, whereas the Mega Society cuts off at the 99.9999th percentile (one in one million). The memberless Grail Society claims to accept one in 100 billion people—no one has applied so far.

Although members of IQ societies do not fit a single profile, they often join in search of a sense of belonging. "I've heard a lot of people refer to themselves as aliens until they found a group like this," says Peters, who serves as an officer of the Prometheus Society. "But get them all together, and they become extremely talkative—they're up un-



MENSA 1/50 · **INTERTEL** 1/100 · **POETIC GENIUS** 1/200 · **CEREBRALS** 1/300 · **TRIPLE NINE SOCIETY** 1/1,000

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had tendencies toward melancholia."

This idea received wide currency in the 19th and 20th centuries at the hands of psychiatrists and psychoanalysts. Among the great writers, Virginia Woolf, Anne Sexton and Sylvia Plath all committed suicide. Vincent van Gogh did as well, and earlier he had cut off part of his ear to give to a prostitute. Newton sometimes suffered from extreme paranoia, and Galileo, possibly an alcoholic, was often bedridden with depression. Nevertheless, many psychologists have argued that such cases are the exceptions, not the rule. Some positive psychologists today consider creative genius a human strength or virtue.

My 2005 review of the literature, which summarized studies with varied methodologies, indicates that the association between genius and mental illness has considerable strength. Very creative writers tend to obtain higher scores on the psychopathology-related parts of the Minnesota Multiphasic Personality Inventory, a widely accepted personality test. A study using another instrument, the Eysenck Personality Questionnaire, found that extremely creative artists—and high-impact psychologists, for that matter—tend to receive elevated scores on the test's psychoticism scale, meaning that they are, among other things, egocentric, cold, impulsive, aggressive and tough-minded. Last, highly eminent scientists tend to score higher on sections of the Cattell 16 Personality Factor Questionnaire that signify they are withdrawn, solemn, internally preoccupied, precise and critical. All told, top performers are not a very normal bunch.

THE RATE AND INTENSITY OF CERTAIN PSYCHOPATHOLOGIC SYMPTOMS ARE NOTICEABLY HIGHER IN VERY CREATIVE PEOPLE THAN IN OTHERS.

Psychiatric studies bolster these results. The rate and intensity of certain psychopathologic symptoms, such as depression and alcoholism, are noticeably higher in very creative individuals than in the general population. Research also suggests that these divergent thinkers are more likely to come from family lines that are at higher risk for psychopathology. Even if an extraordinary innovator is "normal," his or her family members may not be.

In line with these findings, in 2009 psychiatrist Szabolcs Kéri, now at the University of Szeged in Hungary, found a genetic basis for both creativity and psychosis in a variant of the *neuregulin 1* gene. In this study, Kéri recruited a group of highly creative individuals and found that the participants who had this specific gene variant, which is linked with an increased risk of developing a mental disorder, also scored higher on measures of creativity.

Out-and-out psychosis, however, can shut down creative genius. This tragic reality was dramatically illustrated in the 2001 film *A Beautiful Mind*, the biopic about Nobel laureate John Nash and his struggles with schizophrenia. The costs and burdens of psychological dysfunction are also immediately apparent in the art of the mentally ill, such as the works preserved in the Prinzhorn Collection in Heidelberg, Germany, done by psychiatric patients in the early 20th century. Few if any of these artworks show signs of genius. To quote Dryden again, "wits are sure to madness near allied, and thin partitions do their bounds divide."

Recent research conducted by psychologist Shelley Carson of Harvard University and her colleagues has sought to identify these thin partitions. Creative achievement is positively associated both

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til five in the morning." Langdon, who has founded or co-founded several high-IQ societies and now edits the journal of the Mega Society, also reports having joined to find people more like himself.

Others do it for the challenge. "I joined Prometheus just to see if I could," Simpson says. He now deals with the society's membership requests. He receives about two or three a week, although only three or four new members are accepted every year. The admissions process for these societies usually hinges on a score on an approved test, some of which have names such as Mega or Titan. Typical questions include analogies, the manipulation of complex three-dimensional shapes, or word problems that must be translated into equations.

Critics question whether IQ tests measure intelligence accurately, but "genius" societies rarely claim to represent true genius: the merging of intellect, creativity and outstanding achievement. Peters notes that her high-IQ colleagues are acutely aware of their own ignorance. Simpson concurs. "None of us consider ourselves a 'genius,'" he says. "Well, maybe there's this one guy, but he hasn't been in the society for a while now."

Lena Groeger is a science journalist based in New York City.

INTERNATIONAL SOCIETY FOR PHILOSOPHICAL ENQUIRY	ONE IN A THOUSAND SOCIETY	VERTEX SOCIETY	PROMETHEUS SOCIETY	MEGA SOCIETY
1/1,000	1/1,000	1/11,000	1/11,000	1/1,000,000

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PABLO PICASSO'S CHAOTIC PROCESS

In his dozens of sketches for *Guernica* (*right*), Picasso explored numerous styles. A sampling of his drawings of the bull (*below*) reveal the breadth of his exploration. Hunting widely for answers, abandoning some ideas and backtracking to earlier concepts (*red circle*) are hallmarks of a theory of creativity known as blind variation and selective retention.

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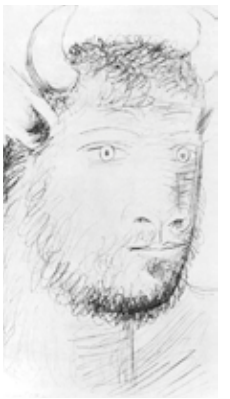

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with cognitive disinhibition—openness to supposedly extraneous ideas, images or stimuli that are normally filtered out before they can reach conscious awareness—and higher intelligence and greater working memory. These mental capacities can potentially ameliorate the negative effects of cognitive disinhibition and even channel them to more useful ends. This synergy may well constitute the cognitive basis for serendipity. Not everybody would be able to work out the profound implications of such humdrum events as water overflowing a bathtub or an apple falling from a tree. But Archimedes and Newton did.

Thinking Outside the Box

Archimedes and Newton both worked in scientific fields, raising the possibility that their brands of creativity may have been similar. A more revealing question might be to investigate how their route to original thought compares with that of a superlative writer or musician. A physicist's way of thinking has little, if anything, in common with that of a painter. For example, learning how to solve a differential equation has as much utility for a painter as learning linear perspective has for a physicist—zero in most cases. Yet the themes uniting geniuses, as discussed earlier, suggest that a common

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creative principle may exist. Domain expertise, such as the knowledge of advanced problem-solving strategies, supports thinking that is routine, even algorithmic—it does not inherently lead to the generation of novel, useful and surprising ideas. Something else must permit a person to go beyond tradition and training to reach the summit of genius.

According to a theory proposed in 1960 by psychologist Donald Campbell, creative thought emerges through a process or procedure he termed blind variation and selective retention (BVSR). In short, a creator must try out ideas that might fail before hitting on a breakthrough. Campbell did not precisely define what counts as a blind variation, nor did he discuss in any detail the psychological underpinnings of the process he described. As a result, his ideas were left open to criticism.

Using a mixture of historical analyses, laboratory experiments, computer simulations, mathematical models and case studies, I have devoted the past 25 years to developing BVSR into a comprehensive theory of creative genius in all domains. The blindness of BVSR merely means that ideas are produced without foresight into their eventual utility. The creator must engage in trial-and-error or generate-and-test procedures to determine the worth of an idea. Two common phenomena characterize BVSR thinking: superfluity and backtracking. Superfluity means that the creator generates a variety of ideas, one or more of which turn out to be useless. Backtracking signifies that the creator must often return to an earlier approach after blindly going off in the wrong direction. Superfluity and backtracking are often found together in the same creative episode. Exploring the wrong track obliges a return to options that had been originally cast aside.

The reflections of Hermann von Helmholtz, a prolific physicist with numerous creative breakthroughs to his name, capture this process of discovery:

> I had to compare myself with an Alpine climber, who, not knowing the way, ascends slowly and with toil, and is often compelled to retrace his steps because his progress is stopped; sometimes by reasoning, and sometimes by accident, he hits upon traces of a fresh path, which again leads him a little further; and finally, when he has reached the goal, he finds to his annoyance a royal road on which he might have ridden up if he had been clever enough to find the right starting point at the outset.

COGNITIVE DISINHIBITION, HIGHER INTELLIGENCE AND GREATER WORKING MEMORY MAY CONSTITUTE THE BASIS FOR SERENDIPITY.

This account of venturing blindly into uncharted territory and retracing steps resonates with evidence from other eminent creators. As Einstein once said, "If we knew what we were doing, we wouldn't call it research."

To see superfluity and backtracking in practice, consider the sketches that Pablo Picasso produced in preparation for his 1937 *Guernica* painting. Among them are clearly "superfluous" sketches, which have a human head on a bull's body (for example, sketches 19 and 22 on the opposite page). Picasso soon discovered that this was a dead end and backtracked to an earlier bull's head drawing (15), before continuing to the final two sketches (26 and 27). Notice that the artist went too far in one direction in the last sketch, from which he backtracked yet again. Even more telling, after that last sketch Picasso largely reversed himself to a much earlier formulation (11), which shares the most unique features with the final version: the widely separated eyes, the thin-lipped open mouth with tongue, the menacing rather than inert visage and the Cubist rather than neoclassic style. These sketches are typical of blind variations both in the arts and in the sciences.

Only further research can expand the theory into a comprehensive, predictive model whose claims can be thoroughly tested. Even so, BVSR can help us make sense of certain quirks of creative geniuses, including their personality traits and developmental experiences. Although they devote considerable time to achieving expertise, they also pursue other hobbies. Their openness to new ideas and their breadth of interests infuse them with seemingly irrelevant stimulation that can enrich blind variations.

As 19th-century German philosopher Arthur Schopenhauer said, "Talent hits a target no one else can hit; genius hits a target no one else can see." Exceptional thinkers, it turns out, stand on common ground when they launch their arrows into the unknown. M

MORE TO EXPLORE

- **Creativity and Discovery as Blind Variation: Campbell's (1960) BVSR Model after the Half-Century Mark.** D. K. Simonton in *Review of General Psychology,* Vol. 15, No. 2, pages 158–174; June 2011.
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RATIONAL AND IRRATIONAL THOUGHT:

THE THINKING THAT IQ TESTS MISS

Why smart people sometimes do dumb things

BY KEITH E. STANOVICH

No doubt you know several folks with perfectly respectable IQs who repeatedly make poor decisions. The behavior of such people tells us that we are missing something important by treating intelligence as if it encompassed all cognitive abilities. I coined the term "dysrationalia" (analogous to "dyslexia"), meaning the inability to think and behave rationally despite having adequate intelligence, to draw attention to a large domain of cognitive life that intelligence

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tests fail to assess. Although most people recognize that IQ tests do not measure every important mental faculty, we behave as if they do. We have an implicit assumption that intelligence and rationality go together—or else why would we be so surprised when smart people do foolish things?

It is useful to get a handle on dysrationalia and its causes because we are beset by problems that require increasingly more accurate, rational responses. In the 21st century, shallow processing can lead physicians to choose less effective medical treatments, can cause people to fail to adequately assess risks in their environment, can lead to the misuse of information in legal proceedings, and can make parents resist vaccinating their children. Millions of dollars are spent on unneeded projects by government and private industry when decision makers are dysrationalic, billions are wasted on quack remedies, unnecessary surgery is performed and costly financial misjudgments are made.

IQ tests do not measure dysrationalia. But as I show in my 2010 book, *What Intelligence Tests Miss: The Psychology of Rational Thought*, there are ways to measure dysrationalia and ways to correct it. Decades of research in cognitive psychology have suggested two causes of dysrationalia. One is a processing problem, the other a content problem. Much is known about both of them.

The Case of the Cognitive Miser

The processing problem comes about because we tend to be cognitive misers. When approaching a problem, we can choose from any of several cognitive mechanisms. Some mechanisms have great computational power, letting us solve many problems with great accuracy, but they are slow, require much concentration and can interfere with other cognitive tasks. Others are comparatively low in computational power, but they are fast, require little concentration and do not interfere with other ongoing cognition. Humans are cognitive misers because our basic tendency is to default to the processing mechanisms that require less computational effort, even when they are less accurate.

Are you a cognitive miser? Consider the following problem, taken from the work of Hector Levesque, a computer scientist at the University of Toronto. Try to answer it yourself before reading the solution:

1 **Jack is looking at Anne, but Anne is looking at George. Jack is married, but George is not. Is a married person looking at an unmarried person?**

A) Yes **B) No** **C) Cannot be determined**

More than 80 percent of people choose C. But the correct answer is A. Here is how to think it through logically: Anne is the only person whose marital status is unknown. You need to consider both possibilities, either married or unmarried, to determine whether you have enough information to draw a conclusion. If Anne is married, the answer is A: she would be the married person who is looking at an unmarried person (George). If Anne is not married, the answer is still A: in this case, Jack is the married person, and he is looking at Anne, the unmarried person. This thought process is called fully disjunctive reasoning—reasoning that considers all possibilities. The fact that the problem does not reveal whether Anne is or is not married suggests to people that they do not have enough information, and they make the easiest inference (C) without thinking through all the possibilities.

Most people can carry out fully disjunctive reasoning when they are explicitly told that it is necessary (as when there is no option like "cannot be determined" available). But most do not

ISTOCKPHOTO (*silhouette of man*); STEFAN SCHULZE *iStockphoto* (*wedding rings*)

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automatically do so, and the tendency to do so is only weakly correlated with intelligence.

Here is another test of cognitive miserliness, as described by Nobel Prize–winning psychologist Daniel Kahneman and his colleague Shane Frederick:

= $1.10

2 **A bat and a ball cost $1.10 in total. The bat costs $1 more than the ball. How much does the ball cost?**

Many people give the first response that comes to mind—10 cents. But if they thought a little harder, they would realize that this cannot be right: the bat would then have to cost $1.10, for a total of $1.20. IQ is no guarantee against this error. Kahneman and Frederick found that large numbers of highly select university students at the Massachusetts Institute of Technology, Princeton and Harvard were cognitive misers, just like the rest of us, when given this and similar problems.

Another characteristic of cognitive misers is the "myside" bias—the tendency to reason from an egocentric perspective. In a 2008 study my colleague Richard West of James Madison University and I presented a group of subjects with the following thought problem:

3 **Imagine that the U.S. Department of Transportation has found that a particular German car is eight times more likely than a typical family car to kill occupants of another car in a crash. The federal government is considering restricting sale and use of this German car. Please answer the following two questions: Do you think sales of the German car should be banned in the U.S.? Do you think the German car should be banned from being driven on American streets?**

Then we presented a different group of subjects with the thought problem stated a different way—more in line with the true data from the Department of Transportation at the time, which had found an increased risk of fatalities not in a German car but in an American one:

Imagine that the Department of Transportation has found that the Ford Explorer is eight times more likely than a typical family car to kill occupants of another car in a crash. The German government is considering restricting sale or use of the Ford Explorer. Please answer the following two questions: Do you think sales of the Ford Explorer should be banned in Germany? Do you think the Ford Explorer should be banned from being driven on German streets?

Among the American subjects we tested, we found considerable support for banning the car when it was a German car being banned for American use: 78.4 percent thought car sales should be banned, and 73.7 percent thought the car should be kept off the streets. But for the subjects for whom the question was stated as whether an American car should be banned in Germany, there was a statistically significant difference: only 51.4 percent thought car sales should be banned, and just 39.2 percent thought the car should be kept off German streets, even though the car in question was presented as having exactly the same poor safety record.

This study illustrates our tendency to evaluate a situation from our own perspective. We weigh evidence and make moral judgments with a myside bias that often leads to dysrationalia that is independent of measured intelligence. The same is true for other tendencies of the cognitive miser that have been much studied, such as attribute substitution and conjunction errors; they are at best only slightly related to intelligence and are poorly captured by conventional intelligence tests.

The Mindware Gap

The second source of dysrationalia is a content problem. We need to acquire specific knowledge to think and act rationally. Harvard cognitive scientist David Perkins coined the term "mindware" to refer to the rules, data, procedures, strategies and other cognitive tools (knowledge of probability, logic and scientific inference) that must be retrieved from memory to think rationally. The absence of this knowledge creates a mindware gap—again, something that is not tested on typical intelligence tests.

One aspect of mindware is probabilistic thinking, which can be measured. Try to answer the following problem before you read on:

4 **Imagine that XYZ viral syndrome is a serious condition that affects one person in 1,000. Imagine also that the test to diagnose the disease always indicates correctly that a person who has the XYZ virus actually has it. Finally, suppose that this test occasionally misidentifies a healthy individual as having XYZ. The test has a false-positive rate of 5 percent, meaning that the test wrongly indicates that the XYZ virus is present in 5 percent of the cases where the person does not have the virus.**

Next we choose a person at random and administer the test, and the person tests positive for XYZ syndrome. Assuming we know nothing else about that individual's medi-

ISTOCKPHOTO (*bat and ball*); STEFAN SCHULZE *iStockphoto (car)*; ISTOCKPHOTO (*hypodermic*)

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WE ASSUME INTELLIGENCE AND RATIONALITY GO TOGETHER. BUT WE SHOULDN'T BE SURPRISED WHEN SMART PEOPLE DO FOOLISH THINGS.

cal history, what is the probability (expressed as a percentage ranging from zero to 100) that the individual really has XYZ?

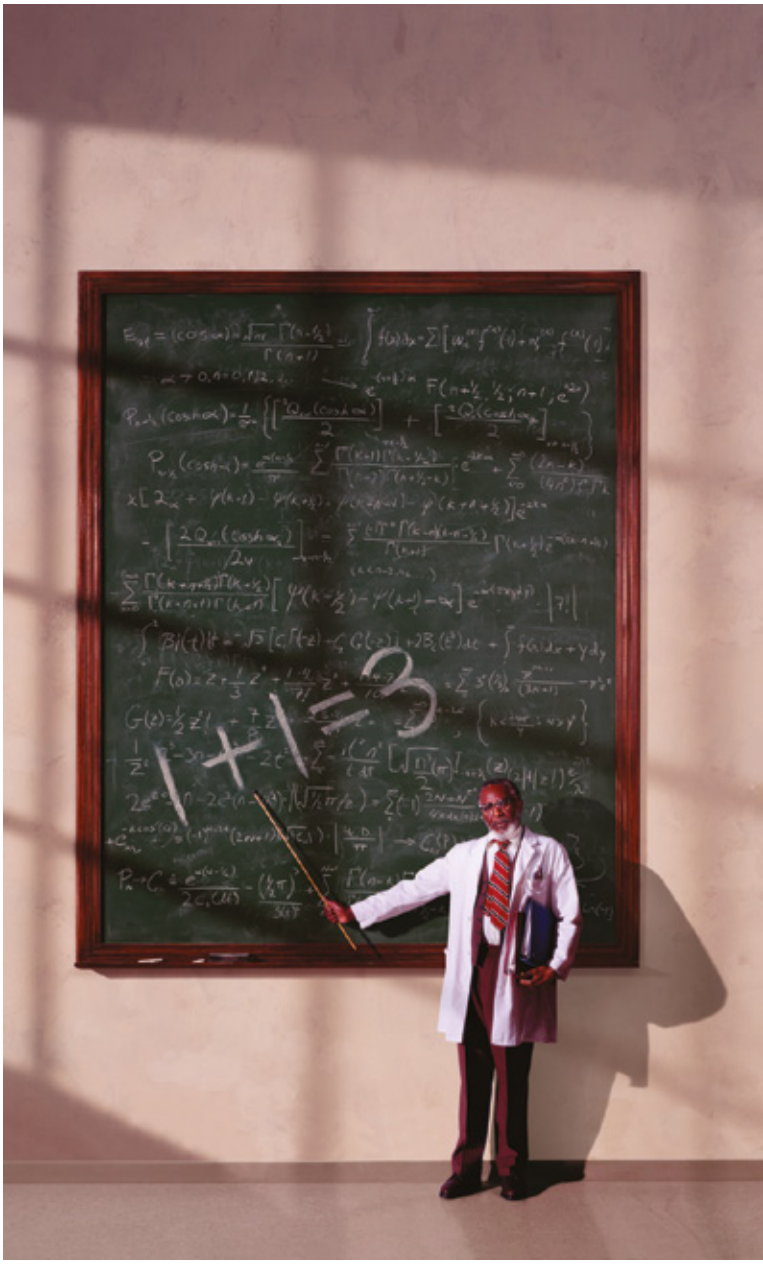
The most common answer is 95 percent. But that is wrong. People tend to ignore the first part of the setup, which states that only one person in 1,000 will actually have XYZ syndrome. If the other 999 (who do not have the disease) are tested, the 5 percent false-positive rate means that approximately 50 of them (0.05 times 999) will be told they have XYZ. Thus, for every 51 patients who test positive for XYZ, only one will actually have it. Because of the relatively low base rate of the disease and the relatively high false-positive rate, most people who test positive for XYZ syndrome will not have it. The answer to the question, then, is that the probability a person who tests positive for XYZ syndrome actually has it is one in 51, or approximately 2 percent.

A second aspect of mindware, the ability to think scientifically, is also missing from standard IQ tests, but it, too, can be readily measured:

5 **An experiment is conducted to test the efficacy of a new medical treatment. Picture a 2 × 2 matrix that summarizes the results as follows:**

	Improvement	No Improvement
Treatment Given	200	75
No Treatment Given	50	15

As you can see, 200 patients were given the experimental treatment and improved; 75 were given the treatment and did



STEVEN BRONSTEIN *Getty Images (man at chalkboard)*; JOE BELANGER *Stockphoto (pill bottle)*

THE AUTHOR

KEITH E. STANOVICH is emeritus professor of applied psychology and human development at the University of Toronto. He is author of seven books about cognition, including *What Intelligence Tests Miss: The Psychology of Rational Thought* (Yale University Press, 2009), which received the 2010 Grawemeyer Award in Education. Stanovich is the winner of the 2012 E. L. Thorndike Career Achievement Award from the American Psychological Association.

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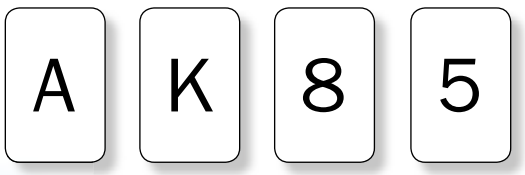
not improve; 50 were not given the treatment and improved; and 15 were not given the treatment and did not improve. Before reading ahead, answer this question with a yes or no: Was the treatment effective?

Most people will say yes. They focus on the large number of patients (200) in whom treatment led to improvement and on the fact that of those who received treatment, more patients improved (200) than failed to improve (75). Because the probability of improvement (200 out of 275 treated, or 200/275 = 0.727) seems high, people tend to believe the treatment works. But this reflects an error in scientific thinking: an inability to consider the control group, something that (disturbingly) even physicians are often guilty of. In the control group, improvement occurred even when the treatment was not given. The probability of improvement with no treatment (50 out of 65 not treated, or 50/65 = 0.769) is even higher than the probability of improvement with treatment, meaning that the treatment being tested can be judged to be completely ineffective.

Another mindware problem relates to hypothesis testing. This, too, is rarely tested on IQ tests, even though it can be reliably measured, as Peter C. Wason of University College London showed. Try to solve the following puzzle, called the four-card selection task, before reading ahead:



6 **As seen in the diagram, four cards are sitting on a table. Each card has a letter on one side and a number on the other. Two of the cards are letter-side up, and two of the cards are number-side up. The rule to be tested is this: for these four cards, if a card has a vowel on its letter side, it has an even number on its number side. Your task is to decide which card or cards must be turned over to find out whether the rule is true or false. Indicate which cards must be turned over.**

Most people get the answer wrong, and it has been devilishly hard to figure out why. About half of them say you should pick A and 8: a vowel to see if there is an even number on its reverse side and an even number to see if there is a vowel on its reverse. Another 20 percent choose to turn over the A card only, and another 20 percent turn over other incorrect combinations. That means that 90 percent of people get it wrong.

Let's see where people tend to run into trouble. They are okay with the letter cards: most people correctly choose A. The difficulty is in the number cards: most people mistakenly choose 8. Why is it wrong to choose 8? Read the rule again: it says that a vowel must have an even number on the back, but it says nothing about whether an even number must have a vowel on the back or what kind of number a consonant must have. (It is because the rule says nothing about consonants, by the way, that there is no need to see what is on the back of the K.) So finding a consonant on the back of the 8 would say nothing about whether the rule is true or false. In contrast, the 5 card, which most people do not choose, is essential. The 5 card might have a vowel on the back. And if it does, the rule would be shown to be false because that would mean that not all vowels have even numbers on the back. In short, to show that the rule is not false, the 5 card must be turned over.

When asked to prove something true or false, people tend to focus on confirming the rule rather than falsifying it. This is why they turn over the 8 card, to confirm the rule by observing a vowel on the other side, and the A card, to find the confirming even number. But if they thought scientifically, they would look for a way to falsify the rule—a thought pattern that would immediately suggest the relevance of the 5 card (which might contain a disconfirming vowel on the back). Seeking falsifying evidence is a crucial component of scientific thinking. But for most people, this bit of mindware must be taught until it becomes second nature.

Dysrationalia and Intelligence

The modern period of intelligence research was inaugurated by Charles Spearman in a famous paper published in 1904 in the *American Journal of Psychology*. Spearman found that performance on one cognitive task tends to correlate with peformance on other cognitive tasks. He termed this correlation the positive manifold, the belief that all cognitive skills will show substantial correlations with one another. This belief has dominated the field ever since.

Yet as research in my lab and elsewhere has shown, rational thinking can be surprisingly dissociated from intelligence. Individuals with high IQs are no less likely to be cognitive misers than those with lower IQs. In a Levesque problem, for

FAST FACTS

WHO ARE YOU CALLING "SMART"?

1. Traditional IQ tests miss some of the most important aspects of real-world decision making. It is possible to test high in IQ yet to suffer from the logical-thought defect known as dysrationalia.
2. One cause of dysrationalia is that people tend to be cognitive misers, meaning that they take the easy way out when trying to solve problems, often leading to solutions that are wrong.
3. Another cause of dysrationalia is the mindware gap, which occurs when people lack the specific knowledge, rules and strategies needed to think rationally.
4. Tests do exist that can measure dysrationalia, and they should be given more often to pick up the deficiencies that IQ tests miss.

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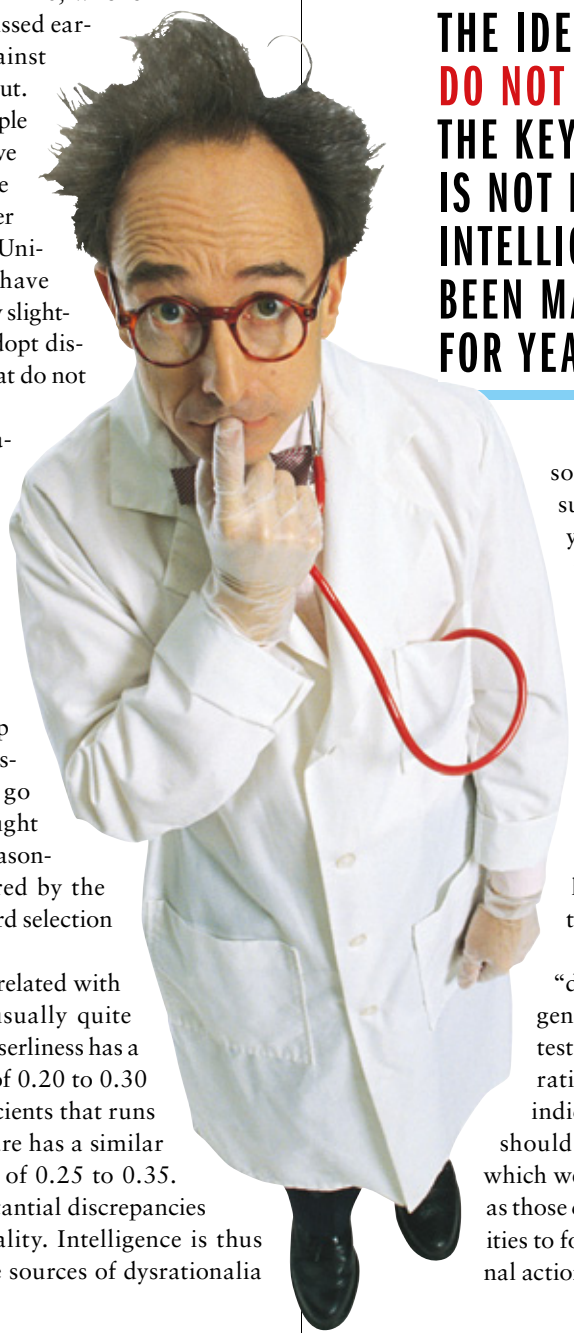
instance (the "Jack is looking at Anne, who is looking at George" problem discussed earlier), high IQ is no guarantee against the tendency to take the easy way out. No matter what their IQ, most people need to be told that fully disjunctive reasoning will be necessary to solve the puzzle, or else they won't bother to use it. Maggie Toplak of York University in Toronto, West and I have shown that high-IQ people are only slightly more likely to spontaneously adopt disjunctive reasoning in situations that do not explicitly demand it.

For the second source of dysrationalia, mindware deficits, we would expect to see some correlation with intelligence because gaps in mindware often arise from lack of education, and education tends to be reflected in IQ scores. But the knowledge and thinking styles relevant to dysrationalia are often not picked up until rather late in life. It is quite possible for intelligent people to go through school and never be taught probabilistic thinking, scientific reasoning, and other strategies measured by the XYZ virus puzzle and the four-card selection task described earlier.

When rational thinking is correlated with intelligence, the correlation is usually quite modest. Avoidance of cognitive miserliness has a correlation with IQ in the range of 0.20 to 0.30 (on the scale of correlation coefficients that runs from 0 to 1.0). Sufficient mindware has a similar modest correlation, in the range of 0.25 to 0.35. These correlations allow for substantial discrepancies between intelligence and rationality. Intelligence is thus no inoculation against any of the sources of dysrationalia I have discussed.



GETTY IMAGES

Cutting Intelligence Down to Size

The idea that IQ tests do not measure all the key human faculties is not new; critics of intelligence tests have been making that point for years. Robert J. Sternberg of Cornell University and Howard Gardner of Harvard talk about practical intelligence, creative intelligence, interpersonal intelligence, bodily-kinesthetic intelligence, and the like. Yet appending the word "intelligence" to all these other mental, physical and social entities promotes the very assumption the critics want to attack. If you inflate the concept of intelligence, you will inflate its close associates as well. And after 100 years of testing, it is a simple historical fact that the closest associate of the term "intelligence" is "the IQ test part of intelligence." This is why my strategy for cutting intelligence down to size is different from that of most other IQ-test critics. We are missing something by treating intelligence as if it encompassed all cognitive abilities.

THE IDEA THAT IQ TESTS DO NOT MEASURE ALL THE KEY HUMAN FACULTIES IS NOT NEW; CRITICS OF INTELLIGENCE TESTS HAVE BEEN MAKING THAT POINT FOR YEARS.

My goal in proposing the term "dysrationalia" is to separate intelligence from rationality, a trait that IQ tests do not measure. The concept of dysrationalia, and the empirical evidence indicating that the condition is not rare, should help create a conceptual space in which we value abilities at least as important as those currently measured on IQ tests—abilities to form rational beliefs and to take rational action. M

MORE TO EXPLORE

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- **Rationality and the Reflective Mind.** Keith E. Stanovich. Oxford University Press, 2011.
- **Thinking, Fast and Slow.** Daniel Kahneman. Farrar, Straus and Giroux, 2011.

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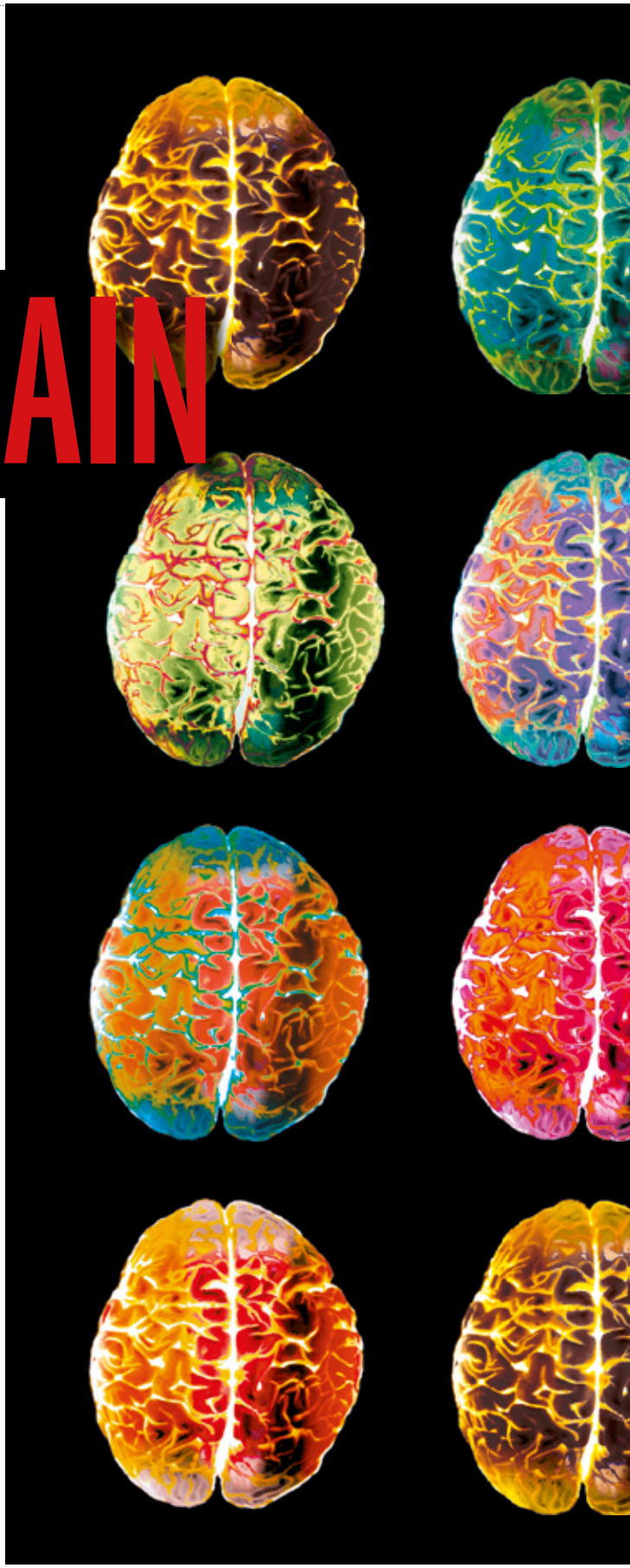
WHAT DOES A SMART BRAIN LOOK LIKE?

BY RICHARD J. HAIER

A NEW NEUROSCIENCE OF INTELLIGENCE IS REVEALING THAT NOT ALL BRAINS WORK IN THE SAME WAY



We all know someone who is not as smart as we are—and someone who is smarter. At the same time, we all know people who are better or worse than we are in a particular area or task, say, remembering facts or performing rapid mental math calculations. These variations in abilities and talents presumably arise from differences among our brains, and many studies have linked certain very specific tasks with cerebral activity in localized areas. Answers about how the brain as a whole integrates activity among areas, however, have proved elusive. Just what does a "smart" brain look like?

Now, for the first time, intelligence researchers are beginning to put together a bigger picture. Imaging studies are uncovering clues to how neural structure and function give rise to individual differences in

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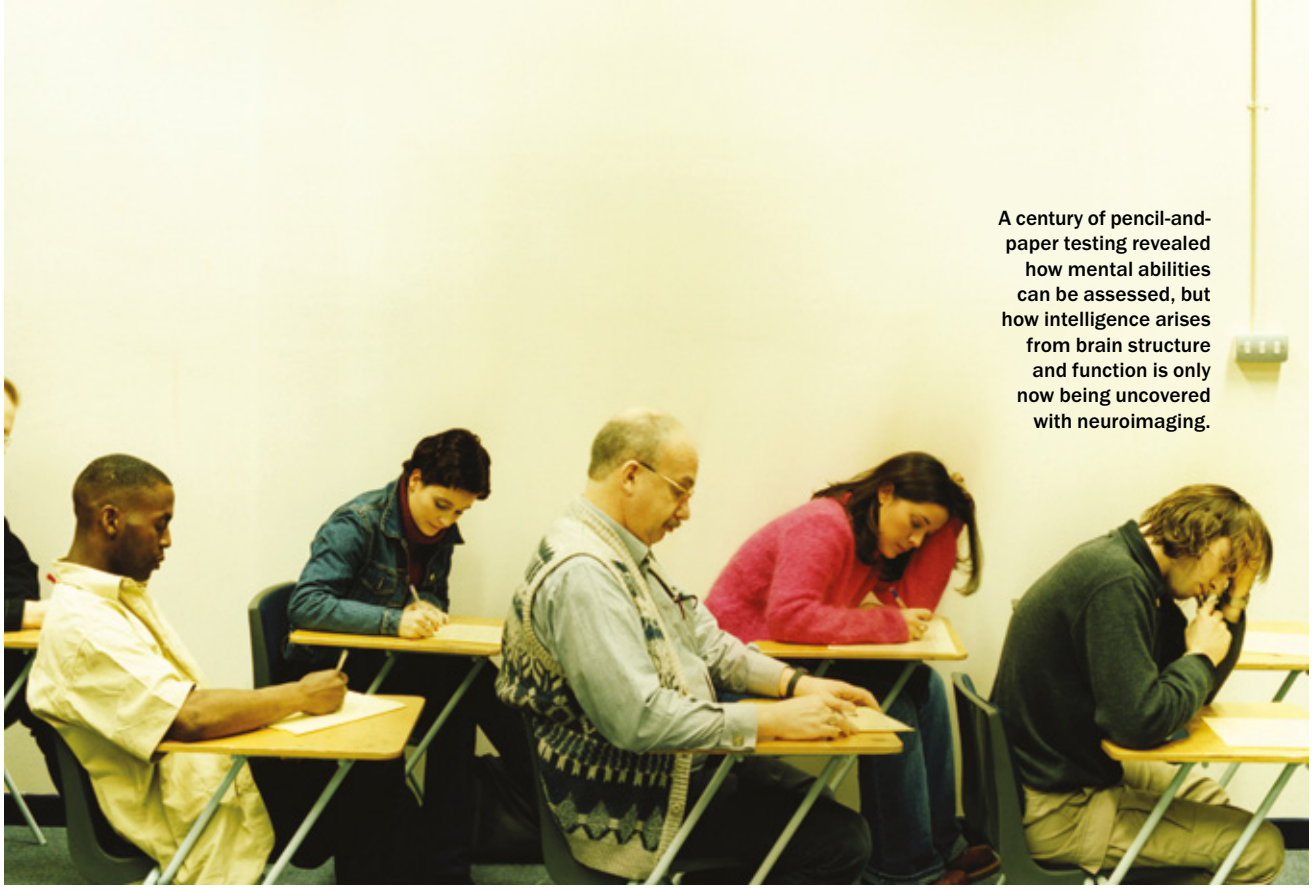

A century of pencil-and-paper testing revealed how mental abilities can be assessed, but how intelligence arises from brain structure and function is only now being uncovered with neuroimaging.

intelligence. The results so far are confirming a view many experts have had for decades: not all brains work in the same way. People with the same IQ may solve a problem with equal speed and accuracy, but using a different combination of brain areas. [For more on IQ and intelligence, see "Rational and Irrational Thought: The Thinking That IQ Tests Miss," by Keith E. Stanovich, on page 12.]

Men and women show group average differences on neuroimaging measures, as do older and younger groups, even at the same level of intelligence. But newer studies are demonstrating that individual differences in brain structure and function, as they relate to intelligence, are key—and the latest studies have exposed only the tip of the iceberg. These studies hint at a new definition of intelligence, based on the size of certain brain areas and the efficiency of information flow among them. Even more tantalizing, brain scans soon may be able to reveal an individual's aptitude for certain academic subjects or jobs, enabling accurate and useful education and career counseling. As we learn more about intelligence, we will better understand how to help individuals fulfill or perhaps enhance their intellectual potential and success.

For 100 years intelligence research relied on pencil-and-paper testing for metrics such as IQ. Psychologists used statistical methods to characterize the different components of intelligence and how they change over people's lifetimes. They determined that virtually all tests of mental ability, irrespective of content, are positively related to one another—that is, those who score high on one test tend to score high on the others. This fact implies that all tests share a common factor, which was dubbed *g*, a general factor of intelligence. The *g* factor is a powerful predictor of success and is the focus of many studies.

In addition to the *g* factor, psychologists also have established other primary components of intelligence, including spatial, numerical and verbal factors, reasoning abilities known as fluid intelligence, and knowledge of factual information, called crystallized intelligence. But the brain mechanisms and structures underlying *g* and the other factors could not be inferred from test scores or even from individuals with brain damage and thus remained hidden.

The advent of neuroscience techniques about 25 years ago finally offered a way forward. New methods, particularly neuroimaging, now allow a different approach to defining intelligence based on physical properties of the brain. In 1988 my colleagues and I at the University of California, Irvine, conducted one of the first studies to use such techniques. Using positron-emission tomography (PET), which produces images of metabolism in the brain by detecting the amount of low-level radioactive glucose

FAST FACTS

SMART BRAINS REVEALED

1. Brain structure and metabolic efficiency may underlie individual differences in intelligence, and imaging research is pinpointing which regions are key players.
2. Smart brains work in many different ways. Women and men who have the same IQ show different underlying brain architectures.
3. The latest research suggests that an individual's pattern of gray and white matter might underlie his or her specific cognitive strengths and weaknesses.

PRECEDING PAGES: SCIENCE SOURCE; THIS PAGE: PAUL THOMAS *Getty Images*

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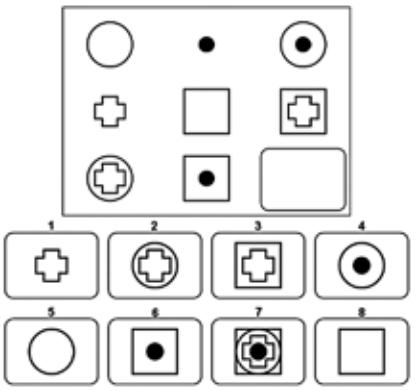
used by neurons as they fire, we traced the brain's energy use while a small sample of volunteers solved nonverbal abstract reasoning problems on a test called the Raven's Advanced Progressive Matrices [*see illustration at right*].

This test is known to be a good indicator of *g*, so we were hoping to answer the question of where general intelligence arises in the brain by determining which areas showed increased activation while solving the test problems. To our surprise, greater energy use (that is, increased glucose metabolism) was associated with *poorer* test performance. Smarter people were using less energy to solve the problems—their brains were more efficient.

The next obvious question was whether energy efficiency can arise through practice. In 1992 we used PET before and after subjects learned the computer game Tetris (a fast-paced visuospatial puzzle), and we found less energy use in several brain areas after 50 days of practice and increased skill. The data suggest that over time the brain learns what areas are not necessary for better performance, and activity in those areas diminishes—leading to greater overall efficiency. Moreover, the individuals in the study with high *g* showed more brain efficiency after practice than the people with lower *g*.



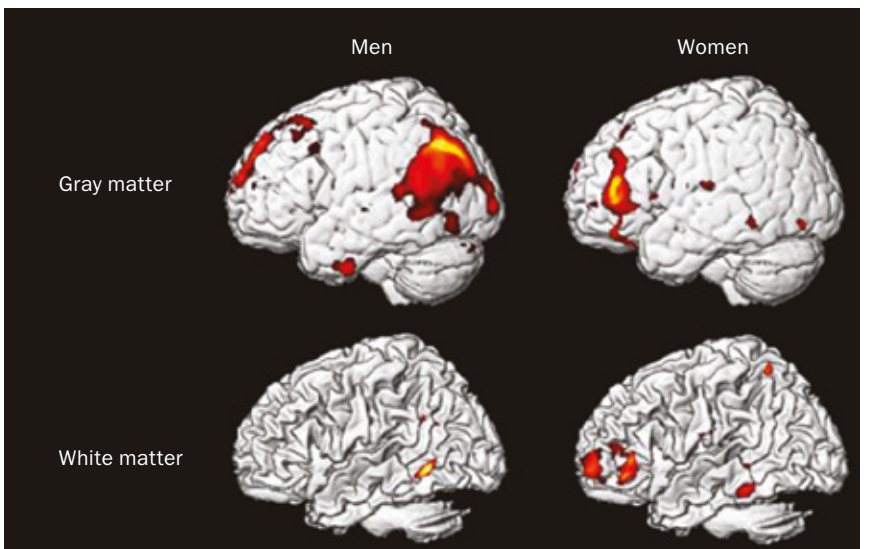
Which of the eight options correctly completes the matrix? This type of abstract reasoning problem is similar to those on the Raven's test, a good indicator of general intelligence. (The answer is number 7.)

By the mid-1990s we were focusing on efficiency as a key concept for understanding intelligence. But then, in 1995, we discovered a difference in the way male and female brains work, giving us our first clue to what we know today: the concept of efficiency depends on the type and difficulty of tasks involved, and there are individual and group differences in brain function during problem solving, depending on who is doing the thinking. In the 1995 study we tested a specific mental ability—mathematical reasoning. We selected college students with either very high or average SAT math scores and used PET to investigate their brain function while they solved mathematical reasoning problems. Unlike the *g* studies, this study showed the people with high math ability using *more* brain energy in a certain region (the temporal lobes), but this was true only for the men and not for the women—even though both men and women performed at the same level on the test.

Gender Matters

These observations have since been replicated by us and other researchers, especially in studies using advanced electroencephalographic mapping techniques. In addition to these experiments showing differences in brain function, brain *structure* also seems to play a role—studies have suggested that other gender differences in cognition, such as the tendency for men to have better visuospatial ability, may be rooted in brain architecture.

For example, in a series of papers published in *NeuroImage* starting in 2004, we used structural MRI scans to investigate correlations between gray and white matter volume and scores on intelligence tests. Gray matter, made up of neuron cell bodies, does the computational work of the brain. White matter enables communication among regions of gray matter via axons, brain cells' long, wirelike appendages. Our studies point to a network of areas distributed throughout the brain where more gray or white



The structural roots of intelligence may differ by gender. In women higher IQ scores are associated with more gray and white matter in frontal language areas, whereas in men higher IQ correlates with more gray matter in posterior sensory-integration areas.

COURTESY OF RACHAEL GRAZIOPLENE (*top*); SCIENTIFIC AMERICAN MIND; SOURCE: "SEX DIFFERENCES IN *N*-ACETYLASPARTATE CORRELATES OF GENERAL INTELLIGENCE: AN H-MRS STUDY OF NORMAL HUMAN BRAIN," BY R. E. JUNG ET AL., IN *NEUROIMAGE*, VOL. 26, NO. 3; JULY 2005 (*bottom*)

THE AUTHOR

RICHARD J. HAIER is professor emeritus in the School of Medicine at the University of California, Irvine. He received the Distinguished Contributor Award in 2012 from the International Society for Intelligence Research. Haier's intelligence research was featured on *NOVA Science Now* in 2012.

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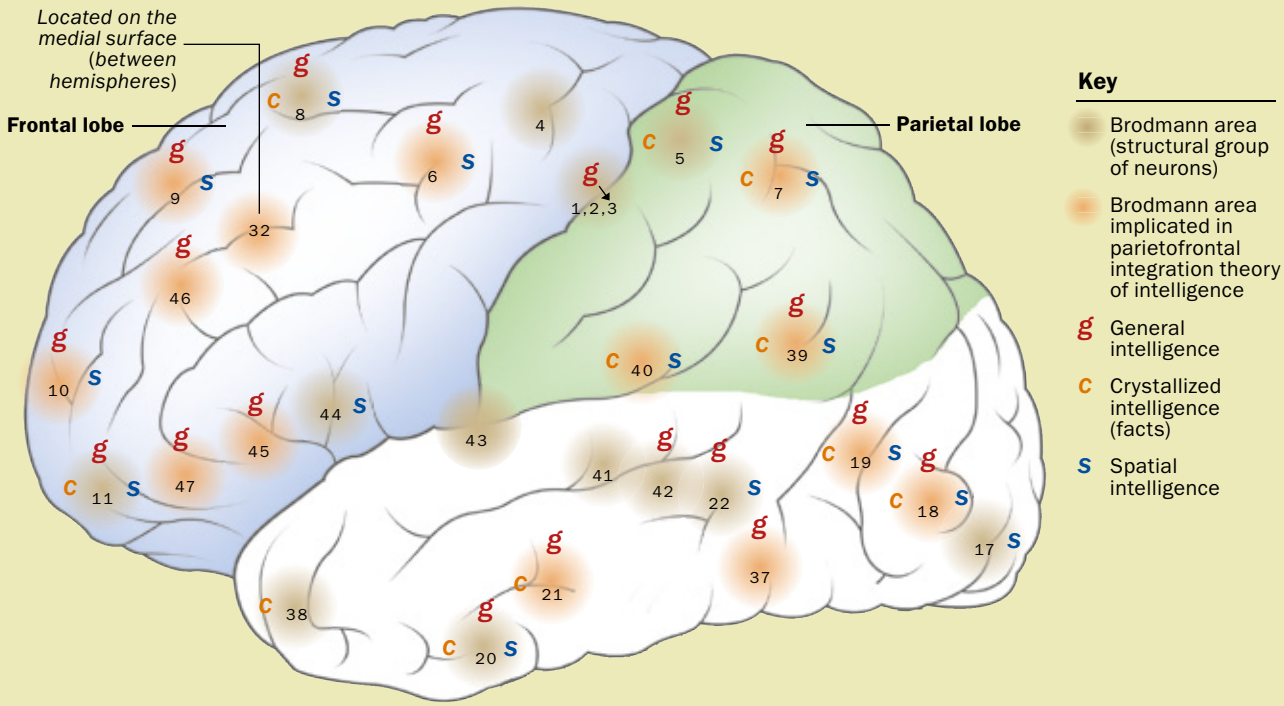
The Neural Roots of Intelligence


Located on the medial surface (between hemispheres)
Frontal lobe
Parietal lobe
Key
Brodmann area (structural group of neurons)
Brodmann area implicated in parietofrontal integration theory of intelligence
g General intelligence
c Crystallized intelligence (facts)
s Spatial intelligence

Brain-imaging studies reveal many areas in which the amount of gray matter (neuron bodies) correlates with intelligence test scores. The color patches above indicate the approximate location of the Brodmann areas—structural groupings of neurons numbered according to historical tradition. The letters on each Brodmann area indicate which intelligence factors it is associated with: general (*g*), spatial (s), and crystallized (*c*), or factual, knowledge. Every individual has a unique pattern of gray matter in these areas [see *illustration on opposite page*], giving rise to different cognitive strengths and weaknesses.

Fourteen of the Brodmann areas (*colored orange above*) are consistently implicated in studies of intelligence-related brain structure and function. Neuropsychologist Rex E. Jung of the University of New Mexico and I reviewed the studies and identified this network, calling it the parietofrontal integration theory (P-FIT) because areas in the parietal (*green*) and frontal (*blue*) lobes were consistent across the most studies. Most of the P-FIT areas are involved in computation (frontal areas) and sensory integration (parietal areas), the processing and conscious understanding of sensory information. —*R.J.H.*

matter is related to higher IQ scores. The specific areas in this network are different in men and women, suggesting there are at least two different brain architectures that produce equivalent performance on IQ tests. In general, we found that in women more gray and white matter in frontal brain areas, especially those associated with language, was correlated with IQ scores; in men IQ scores correlated with gray matter in frontal areas and, especially, in posterior areas that integrate sensory information [*see bottom illustration on preceding page*].

Children also show different developmental brain patterns related to IQ, depending on their gender. In a series of imaging studies with large samples, published from 2006 to 2008, neuroscientist Vincent J. Schmithorst, then at the Cincinnati Children's Hospital Medical Center, and his colleagues found that as girls age they show increasing organization—that is, well-defined paths between disparate brain regions—in their right hemisphere. Boys, in contrast, show this developmental trend in their left hemisphere. We do not yet know how these findings relate to behavioral or learning differences, but the research points the way for future studies to determine how brain development relates to boys' and girls' cognition and academic achievement.

A New Definition

Gender differences were merely the first indication that not all brains work the same way. In 2003 we investigated whether we could observe functional variations during passive mental activity without a task assigned. Again we used

SCIENTIFIC AMERICAN MIND; SOURCES: "THE PARIETO-FRONTAL INTEGRATION THEORY (P-FIT) OF INTELLIGENCE: CONVERGING NEUROIMAGING EVIDENCE," BY R. E. JUNG AND R. J. HAIER, IN *BEHAVIORAL AND BRAIN SCIENCES*, VOL. 30, NO. 2; APRIL 2007, AND "WORKING MEMORY CAPACITY AND PROCESSING EFFICIENCY PREDICT FLUID BUT NOT CRYSTALLIZED AND SPATIAL INTELLIGENCE: EVIDENCE SUPPORTING THE NEURAL NOISE HYPOTHESIS," BY K. MARTÍNEZ AND R. COLOM, IN *PERSONALITY AND INDIVIDUAL DIFFERENCES*, VOL. 46, NO. 3; FEBRUARY 2009

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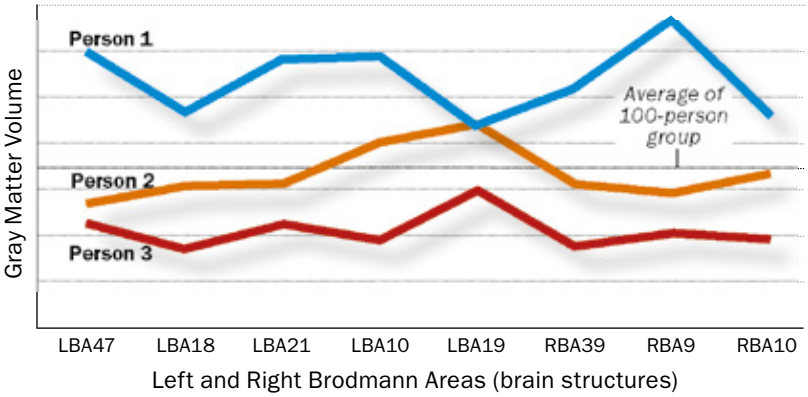
PET in two groups of volunteers selected for high or average scores on the Raven's test. Both groups watched the same videos passively with no problem solving or other task demands. The group with high test scores showed different brain activations in posterior visual-processing areas as compared with the average group. The data suggest that early stages of information processing are more engaged in individuals with higher intelligence, perhaps suggesting that the smarter people in the study were not watching the videos "passively" after all—they were actively processing what they were seeing.

Although more and more evidence shows that problem solving and even passive sensory processing do not look exactly the same in every brain, we still are able to identify a network of areas that seem to give rise to intelligence in general. In fact, defining the crucial regions and connections will help us delineate exactly how each person's brain works—every individual uses some combination of these areas in a unique way.

How Brains Stack Up



Brain profiles of three individuals show the amount of gray matter each has in areas associated with intelligence, called P-FIT areas [*for more information about these brain areas, see box on opposite page*]. The individual who scored the highest in the 100-person study group on tests of general intelligence, or *g*, has far more than the group's average amount of gray matter in every area (*blue line*). The other two subjects (*red* and *orange lines*) had identical, average *g* scores, but their pattern of gray matter differs. Further research could reveal how such differences correspond to an individual's cognitive strengths and weaknesses.

In 2007 neuropsychologist Rex E. Jung of the University of New Mexico and I reviewed the 37 neuroimaging studies on intelligence that existed at that point. In the journal *Behavioral and Brain Sciences,* we identified salient brain areas found in both structural and functional studies with some consistency. The 14 areas are distributed throughout the brain, refuting the long-held notion that the frontal lobes alone are the primary location for intelligence. In particular, parts of the parietal lobes, located under the crown of the head and known to be involved in sensory integration, play a significant role. Because areas in the parietal and frontal lobes were most represented across the studies we reviewed, we called our theory of intelligence based on this network the parieto-frontal integration theory (P-FIT). The 14 P-FIT areas are involved in attention, memory, language and sensory processing [*see box on opposite page*].

EVERY INDIVIDUAL USES SOME COMBINATION OF INTELLIGENCE-RELATED BRAIN AREAS IN A UNIQUE WAY.

Identifying the P-FIT network implies a new definition of general intelligence based on the brain's measurable characteristics. Both the amount of gray matter in certain P-FIT areas and the rate of information flow among these areas are likely to play key roles in intelligence. In 2009 studies at University Medical Center Utrecht in the Netherlands and the Chinese Academy of Sciences in Beijing used functional MRI to determine the efficiency of connections throughout the brain, pinpointing P-FIT areas where connectivity was especially associated with IQ scores. The findings support the idea that general intelligence not only arises from gray matter volume but also depends to a large extent on the white matter connections between crucial gray matter areas. More efficient connections allow information to flow faster—and quick processing times seem to go hand in hand with a high IQ.

Everyone Is Unique

But IQ scores do not tell the whole story—not even close. Intelligence seems to arise from varying combinations of the P-FIT brain areas in different people, which may explain each person's individual strengths and weaknesses. The challenges of identifying these patterns are well illustrated by the extremely rare cases of autistic savants. Daniel Tammet, for example, is a young adult with autism who has uncommonly high IQ scores. He sees numbers as colors and shapes, which allowed him to memorize the value of pi to 22,514 digits. He also learned to converse fluently in Icelandic after only seven days of instruction. Tammet leads an independent life and wrote a best-selling autobiography describing his extraordinary numerical and language ability. What would his "brain profile" show?

SCIENTIFIC AMERICAN MIND; SOURCE: COURTESY OF RICHARD J. HAIER

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Although we are not currently able to deduce from a scan of Tammet's brain how his extraordinary abilities arise, the most recent wave of neuroimaging studies has given us clues to how we might one day do exactly that. New studies have found correlations between gray matter in certain areas and specific intelligence factors.

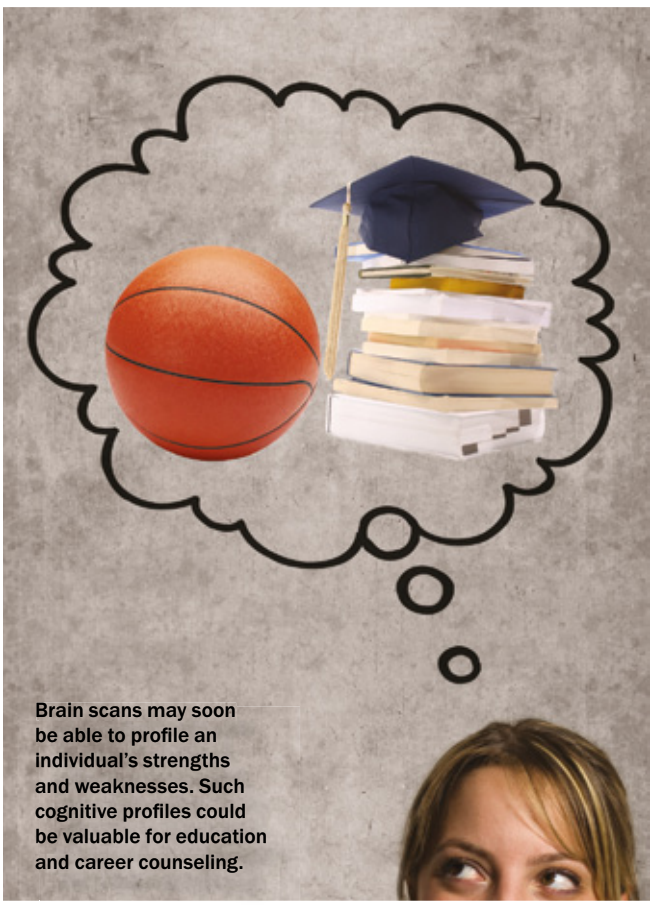
In March 2009 psychologist Robert-

A LEARNING PROGRAM COULD BE TAILORED BASED ON AN INDIVIDUAL STUDENT'S BRAIN CHARACTERISTICS.

to Colom of the Autonomous University of Madrid and his collaborators (including me) reported on the relation between gray matter volume and different intelligence factors in 100 young adults. Each person completed a battery of nine cognitive tests known to indicate different intelligence factors, including *g*, fluid intelligence, crystallized (factual) intelligence and a spatial factor. We found a positive correlation between scores on the *g* factor and the amount of gray matter in several areas predicted by P-FIT. And once we accounted for the common *g* factor, we found that gray matter volume in certain brain areas was related to the other specific intelligence factors. For details of which areas are connected to each factor, see the box on page 22.

One of the most tantalizing ideas to come out of this recent research is the possibility of matching an individual's gray and white matter pattern to his or her *g* and to other specific intelligence factors. In other words, the tissue in P-FIT areas may predict a person's unique pattern of cognitive strengths and weaknesses across a range of mental abilities. These differing brain profiles may explain why two people with an identical IQ score may show very different cognitive abilities. The data from Madrid illustrate this idea nicely [*see illustration on preceding page*]. The person in our volunteer group with the highest *g* score showed far more gray matter than the group's average amount in several P-FIT areas—perhaps not surprisingly. But it is interesting to note that two people with identical *g* scores of 100, the average for the group tested in the study, exhibited different cognitive profiles, suggesting different cognitive strengths and weaknesses.

The idea that we all have our own pattern of variations in brain areas that contribute to different intelligence factors is underscored dramatically by a structural MRI study in March 2009 of 241 patients with brain lesions. Psychologist Jan Gläscher, then at the California Institute of Technology, and his colleagues showed that the site of each lesion was correlated with specific factor scores. For example, perceptual organization suffered—patients had trouble consciously understanding raw information from their senses—when their right parietal lobe was damaged.



Brain scans may soon be able to profile an individual's strengths and weaknesses. Such cognitive profiles could be valuable for education and career counseling.

A Smarter Future

These most recent studies suggest that neuroimaging could one day become a supplement or even a substitute for traditional paper-and-pencil intelligence testing. An individual brain profile could be valuable. In education, for example, a learning program could be tailored for an individual student, at any age, based on that student's brain characteristics. Perhaps vocational success could also be predicted—are there patterns of gray matter across some areas, for example, that make for the best teachers, fighter pilots, engineers or tennis players? People who are seeking a better life with vocational and career consultation certainly will want the choice of having a brain assessment if there are data to support its usefulness.

But it is worth remembering that, contrary to older dogma, the brain is not set in stone or in genetic immutability. Exactly the opposite is true. The brain is plastic—it changes. A brain profile detailing a person's strengths

BURAK PEKAKCAN /*Stockphoto (thought bubble)*; GETTY IMAGES (*basketball*); SHARON DOMINICK /*Stockphoto (books and mortarboard)*

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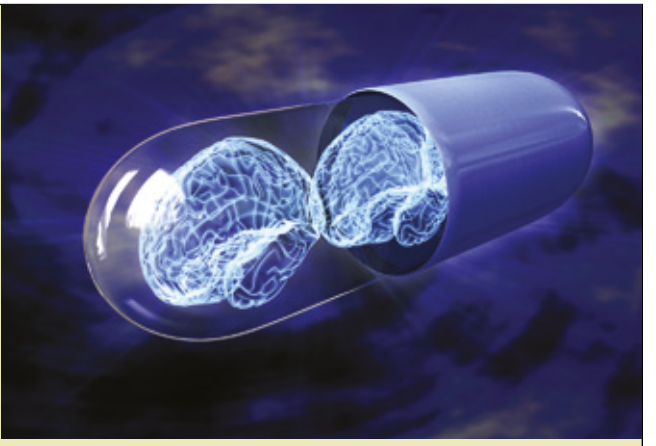
Boosting Healthy Brains



The latest research into the neural roots of intelligence may lead to better drugs and tools for cognitive enhancement. In the future, drugs may enhance the neurotransmitters that regulate communication among the salient brain areas underlying general intelligence or more specific mental abilities. Other drugs could stimulate gray matter growth or white matter integrity in relevant areas. Certainly such advances would be welcome as potential treatments for mental retardation and developmental disabilities. They may also be welcome by any individual looking for more intelligence. [For more on performance-enhancing drugs, see "Turbocharging the Brain," by Gary Stix, on page 102.]

If an effective "IQ pill" becomes available, are the societal and ethical issues the same as for performance-enhancing drugs in sports, or is there a moral imperative that more intelligence is always better than less? Apparently many scientists agree with the latter. An online survey of 1,427 scientists conducted in 2008 by *Nature* found that 20 percent of respondents already use prescription drugs to enhance "concentration" rather than for treating a medical condition. Almost 70 percent of 1,258 respondents who answered the question said they would be willing to risk mild side effects to "boost their brainpower" by taking cognition-enhancing drugs. Eighty percent of all the scientists who responded—even those who did not use these drugs—defended the right of "healthy humans" to take them as work boosters, and more than half said that their use should not be restricted, even for university entrance exams. More than a third said that they would feel pressure to give their children such drugs if they knew other kids at school were also taking them. Few appear to favor the "ignorance is bliss" position.

Intelligence is a critical resource for the development of civilization. As the global economy evolves and small countries compete with larger countries, assessing, developing and even enhancing intellectual talent may well become the neuroscience challenge for the 21st century. —*R.J.H.*

would offer a guide rather than a prescription—perhaps suggesting ways to practice skills or improve education so that a person could become better suited for the activities or careers he or she is most interested in. Fascinating recent studies show that learning to juggle increases the amount of gray matter in brain areas relevant to motor activity. When the training stops, the additional gray matter disappears. Because regional gray matter is related to intelligence, can training beyond conventional education approaches be directed at specific brain areas to increase intelligence? We do not yet know, but the prospect is exciting. Initial reports that memory training can increase intelligence were based on limited measures of intelligence, and, for the most part, they have not been replicated independently.

The next phase of neurointelligence research may include studies designed to answer such questions, including education experiments to determine whether different strategies produce specific brain changes and whether students selected on the basis of their individual brain characteristics are more likely to maximize learning in a particular subject with one educational strategy versus another. The goal would be to enhance current educational decision making by adding customized information about each student's brain. How any specific brain characteristic develops and how it may be influenced are critical, but separate, questions for research.

Whether everyone agrees on precisely the same definition of intelligence or not, progress in neuroscience is inexorable. We will continue to discover how the brain manages the complex information processing that undoubtedly underlies all notions of intelligence. Given the ravages of brain disease, aging, the technical needs of modern societies, the challenges of education and the joy of experiencing the world through intellect, there is some urgency to understand how smart brains work. It is not too early for discussion about the implications of the search for neurointelligence and our willingness to go where the data lead. **M**

MORE TO EXPLORE

- **Why Aren't More Women in Science?** Stephen J. Ceci and Wendy M. Williams. American Psychological Association, 2006.
- **The Parieto-Frontal Integration Theory (P-FIT) of Intelligence: Converging Neuroimaging Evidence.** Rex E. Jung and Richard J. Haier in *Behavioral and Brain Sciences,* Vol. 30, No. 2, pages 135–187; 2007.
- **Brain Imaging Studies of Intelligence and Creativity: What Is the Picture for Education?** Rex E. Jung and Richard J. Haier in *Roeper Review,* Vol. 30, No. 3, pages 171–180; 2008.
- **Gray Matter Correlates of Fluid, Crystallized, and Spatial Intelligence: Testing the P-FIT Model.** Roberto Colom, Richard J. Haier, Kevin Head, Juan Álvarez-Linera, María Ángeles Quiroga, Pei Chun Shih and Rex E. Jung in *Intelligence,* Vol. 37, No. 2, pages 124–135; March-April 2009.

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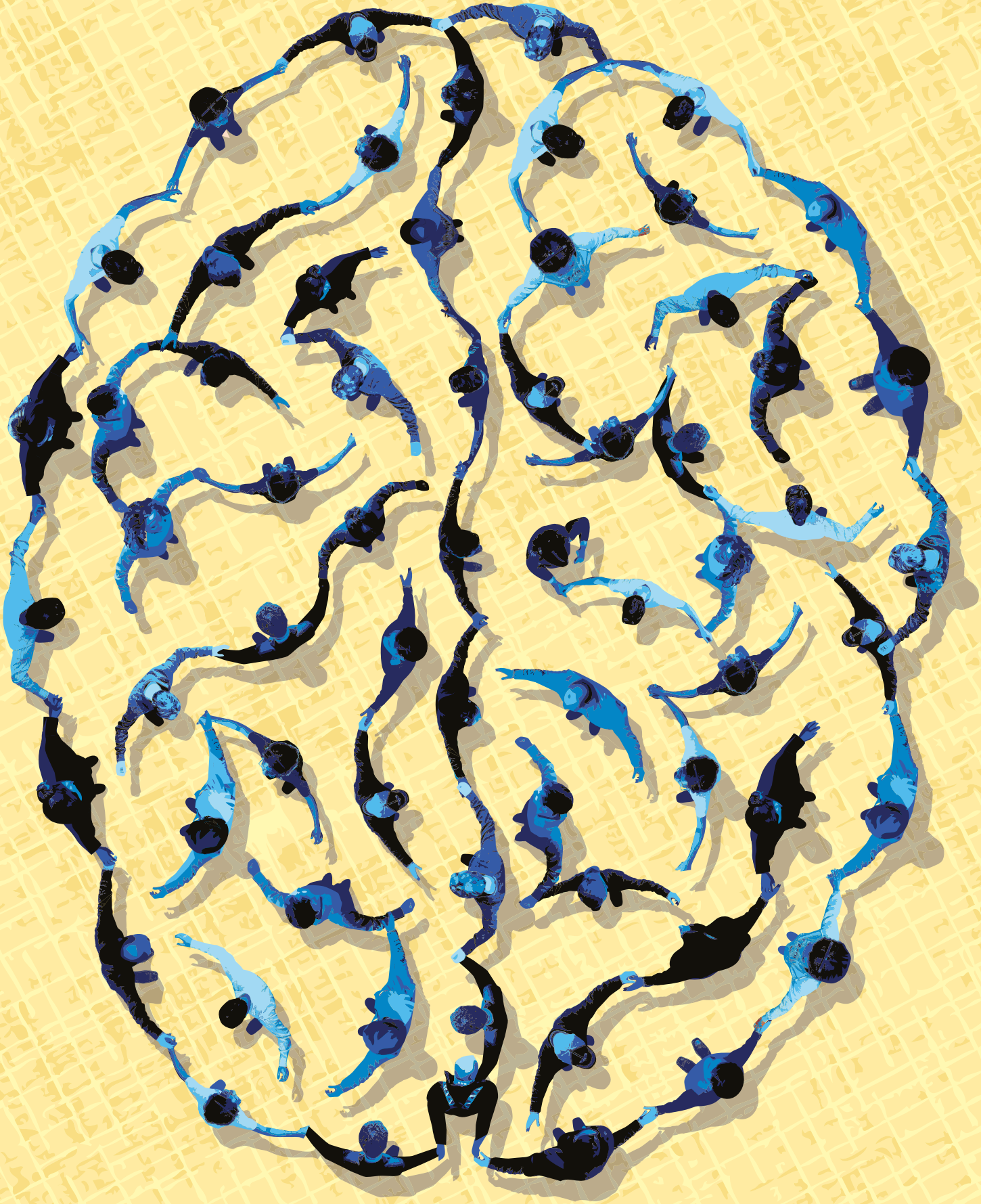

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CREATIVITY IS COLLECTIVE

PERSONAL EXPERIENCES AND CHARACTER TRAITS ALONE MAY NOT BE ENOUGH TO PRODUCE A PRODIGY. IT TAKES A VILLAGE

BY S. ALEXANDER HASLAM, INMACULADA ADARVES-YORNO AND TOM POSTMES

Illustration by Daniel Hertzberg

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The best actors, directors and screenwriters receive Oscars; the top scientists, Nobel Prizes. Society doles out a multitude of awards every year to celebrate the creative achievements of individuals. Such events feed a popular conception that creativity is a gift only certain people possess and constitutes the apotheosis of individuality. Albert Einstein once observed, "Everything that is really great and inspiring is created by the individual who can labor in freedom." In these terms, the straitjacket of groups and of mainstream society is often thought to spell death for creativity. Many see the notion of group creativity as an oxymoron.

But let us think creatively here and challenge the basic assumption that the individual creator is the only critical component of the creative process. Indeed, let us consider the possibility that groups play an essential role in creativity—not only generating and shaping novel products but also ensuring their appreciation and impact. Although this idea might seem preposterous, it has garnered significant scientific support. Last year the three of us, with our colleague Lise Jans, published a review of much of the accumulated data in an article summarizing the current thinking about groups and creativity. We concluded that it is problematic and unhelpful to separate the creativity of individual minds from the communities in which they flourish.

FAST FACTS
WORKING TOGETHER

1. Groups play an essential role in creativity—not only in generating and shaping novel products themselves but also in ensuring their appreciation and impact.
2. A sense of shared social identity provides the motivation for people to stick to a creative project and see it to completion.
3. People's perceptions of creativity depend on whether the creator is "one of us" or "one of them."

Social Identities

Despite the romantic notion that innovation is the province of rugged individuals slaving away in splendid isolation, a scientific focus on individual personality has not yet yielded accurate forecasts of creative behavior. Scholars have scoured the biographies of creative geniuses to find experiences and character traits likely to have contributed to their greatness. Yet they have failed to identify characteristics that powerfully predict which young people will go on to become creative geniuses.

These efforts lack predictive power because they do not take into account the important role that social context plays. The nature and significance of innovation depend on the interaction between an individual's ideas and the time and culture in which he or she lives. If Bruce Springsteen had been born in 1749 rather than 1949, we would have been unlikely ever to hear *Born to Run*. Likewise, if Italian composer Domenico Cimarosa had been born in 1949 rather than 1749, his nearly 80 operas, including the masterpiece *Il matrimonio segreto*, probably would not have seen the light of day.

Such examples speak more generally to the influence that groups exert on creativity. In the 1970s the late psychologists Henri Tajfel and John Turner of the University of Bristol in England developed the concept of social identity, observing that across a range of contexts, people understand themselves not only as individuals but also as members of the groups to which they belong. So a cubist painter—we'll call him "Pablo"—may sometimes think of himself in terms of his personal identity (Pablo), but on other occasions he will understand himself as a cubist, his social identity. In yet other situations, his social identity might be defined with reference to his nationality, gender or religion or to his role in a specific team, club or organization.

Tajfel and Turner argued that when a particular social identity is psychologically salient, such that it determines a person's sense of who he or she is, the group that is the basis for that identity will exert a profound influence on that individual's behavior. Furthermore, the way that person evaluates an action, regardless of whether it is his or her own, will reflect shared understandings of that group. This idea also applies to creative

Pablo Picasso (*left*) likely thought of himself as a cubist painter as well as an antifascist and a Spaniard. Depending on the context, different social identities will influence our behavior.

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Musical groups—such as the Beatles (*left*)—as well as groups of writers, scientists and others, can fuel creativity when group members receive encouragement and constructive feedback from one another.

behavior and its evaluation. For example, as a cubist, Pablo is more likely to be interested in and to appreciate abstract representations of objects, and he will be more likely to paint in accordance with cubist guidelines and preferences.

Social identities also grant people a shared perspective, as well as the ability and motivation to engage in mutual social influence. But when people act in terms of their unique personal identity, they are likely to display creativity by deviating from the norm. In an experiment published in 2007, the three of us asked some college students, who were working in groups, to create posters about "reasons for going to university" and other groups of students to make posters about "fashion at university." With these instructions, we implicitly led the students toward certain group norms. Those told to focus on "reasons" naturally made posters dominated by words, and those directed toward "fashion" created posters populated largely by images.

In a second phase of the study, which came three hours later, we asked the same participants to create a leaflet to advertise the university, a task that could be accomplished equally well with words as with pictures. This time some of the students worked in groups, whereas others made the leaflet on their own. Here we were interested in whether this creative task would be shaped by the group norm that had been established in the earlier phase. It was. We found that when working in a group, participants' creations were generally in line with the group norm established during the poster-making project, whether it centered on images or words. When working individually, however, participants typically departed from the norm of the group they had previously belonged to. Such findings, and those of similar studies, support the claim that the nature of people's creative activity depends on group norms.

Collaborative Spirit

Evidence that social identification shapes creativity might suggest that groups simply stimulate convergent thinking and conformity. Indeed, back in the 1970s, Irving Janis of Yale University proposed that a desire to conform to the group leads to a lack of critical thinking and faulty decision making—a phenomenon called groupthink that he considered the antithesis of creativity. But although group dynamics can sometimes be stifling (or worse), they do not inevitably produce irrational choices or blind support of the group's ideas.

For one thing, group standards shape only one facet of an individual's creativity. Cubist painters, for instance, may use abstract geometric figures in line with the customs of cubism, but their artwork is likely to diverge on other dimensions—for example, in its use of certain colors or themes—that are not restrained by the cubist style.

In addition, far from repressing new ideas, collaborative discussions with friends, colleagues or peers can foster them. As psychologist Vera John-Steiner of the University of New Mexico notes in her 2000 book *Creative Collaboration,* small groups—the Beatles, Bauhaus or the Bloomsbury Group, for instance—routinely spearhead innovation by bouncing ideas off one another as they look for new ways to tackle artistic, theoretical and practical problems.

What is more, solidarity and conformity are essential for creative movements to progress because they allow individuals to cohere around a shared enterprise. In a study published in 2006, we explored this idea by asking small groups of college students to participate in a mock planning process directed at the building of an innovative municipal child care center. Prior to the study, some of the groups went through a procedure that instilled a strong sense of shared social identity, whereas other groups were encouraged to think of themselves as individuals. The groups then met three times over an hour and a half to discuss the fictitious project, which encountered mounting difficulties. First, labor costs increased, and an environmental impact study was needed. Next, they learned that the children's sandbox had traces of toxic elements, parents were threatening to sue, and officials were holding up building approval.

We found that the groups that had initially developed a shared social identity stayed upbeat about the project and continued to support it even as it ran into trouble. On the other hand, those coaxed to see themselves as individuals lost their enthusiasm for the child care center and increasingly argued to abort the project as

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MICHAEL OCHS ARCHIVES *Getty Images*

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time went on. In other words, social—but not personal—identity bolstered enthusiasm and encouraged people to stay with the creative task in the face of challenges. More generally, people seem to need a sense of shared social identity to stick to their creative guns and see revolutionary projects—whether in science, industry, the arts or politics—to completion.

WHEN NORMS ARE HARMFUL FOR A GROUP, IT IS THE MEMBERS WHO FEEL MOST CONNECTED TO THE GROUP WHO ARE THE MOST MOTIVATED TO DEBATE AND RENEGOTIATE THOSE NORMS.

Being solidly committed to the group does not make a person blind to its faults, either. Sometimes the opposite appears to be the case. When norms are harmful for a group, it is actually the members who feel most connected to the group who are the most motivated to debate and renegotiate those norms. In research published in 2012, psychologists Dominic J. Packer of Lehigh University and Christopher T. H. Miners of Queen's University in Ontario asked students to write an opening statement before a meeting in which they were going to discuss alcohol use with their peers, among whom a tendency to party was the norm. The researchers found that the more the participants identified with the group, the more their statements involved creative challenges to that group norm, possibly because those high identifiers felt the greatest responsibility to the group or the most able to effect a transformation. Either way, the research shows that engagement with groups can help stimulate creative ideas for change.

Getting Attention

Groups also play a vital role in the appreciation of groundbreaking achievements. Without tapping into group identity, innovative artists, writers and scientists may well go unrecognized. In his lifetime, Vincent van Gogh could find hardly anyone to buy his unusual paintings. His work garnered attention only when, after his death, a circle of artists, the Postimpressionists, saw his paintings as indicative of a distinctive style that they wanted to emulate in their own work. Similarly, in 1961 the computational models of then graduate student Yoshisuke Ueda were initially barred from publication by his supervisor at Kyoto University because they were seen to be too avant-garde. Once a community of scientists had formed who appreciated Ueda's work, however, his theories transformed the newly emerging field of chaos theory.

Indeed, people are far more likely to support a creative project or endeavor if its instigator is a member of their group. Such insider status helps to dispel the uncertainty that new products introduce by disrupting the status quo. Insiders in organizations are typically antagonistic toward outsiders' contributions, and people often display ethnocentric bias when judging artistic creativity as well. In the performing arts, judges may preferentially bestow accolades on citizens of their own country.

For example, both the U.S. Oscars and the British Academy of Film and Television Arts (BAFTA) awards are meant to judge the objective quality of films. But in an unpublished archival study conducted in 2013, psychologist Niklas Steffens and his colleagues at the University of Queensland in Australia found that since 1968, U.S. actors and actresses have received 80 percent of the Oscars for best actor and best actress but less than half of the BAFTA awards for the same categories. At the same time, British performers have received nearly half the BAFTA awards for best actor or actress but just over 10 percent of the corresponding Oscars.

Experiments confirm that people's perceptions of creativity depend on whether the creator is "one of us" or "one of them." In one study published in 2008, the three of us asked 50 people from the U.K. to evaluate suggestions about the future format of a television show that we said had come from a British Web site. We told another 50 participants that the same ideas had come from a Dutch Web site. In part two of the study, we asked 125 British students to evaluate works of art that we attributed to either British or Dutch college students. In both cases, participants who thought their fellow Brits, the in-group, had authored the products in question judged them to be significantly more creative than did those told that Dutch citizens had generated the same items.

What people actually mean by creativity—and hence how they measure and reward it—also depends on cultural identity. In work published in 2008, psychologists Susannah Paletz, now at the University of Maryland, and Kaiping Peng of the University of California, Berkeley, conducted a survey that included more than 300 students from China and the U.S. to find out what they thought made certain products creative. They tested two very different types of products: a course textbook and a meal cooked by a friend. They found that American students' judgments of creativity were swayed more by the perceived appropriateness of a product (whether it

Even the most creative people need followers. The art of painter Vincent van Gogh (*self-portrait at left*) received widespread recognition only after his death, when it inspired a burgeoning group of artists, the Postimpressionists.

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was, in some sense, good), whereas the judgments of Chinese students were based more on whether the product was something they personally desired. The Americans thus saw creativity more as a matter of taste, and the Chinese saw it more as a matter of appetite.

The tendency for creativity judgments to reflect our social identities also explains some gender bias. In a 2006 paper, psychologist Thomas Morton and his colleagues at the University of Exeter in England reported that male scientists viewed theories explaining how men were superior to women to be better and more creative than those arguing that women were superior to men. This pattern was reversed for female scientists. Both groups also believed that the creative research that supported their own identity-based preferences was deserving of more research funding.

For their part, good creators have a strong sense of their audience and gear their solutions or products to the perceived needs and values of a particular group. Even when work is inspired by the need to separate from a group, a successful creator is familiar with the group from which he or she wishes to deviate.

For example, in the 1970s punk rock bands such as the Sex Pistols wanted to break away from mainstream popular music. Sid Vicious, the Sex Pistols's bassist, called on people to "undermine [the establishment's] pompous authority, reject their moral standards, make anarchy and disorder your trademarks." Ironically, then, the musical establishment of the time gave his band a particular creative force (the desire to rebel), as well as a specific trajectory (something specific to move away from) and appeal (for those disaffected with mainstream popular music). Accordingly, as with other successful creative efforts, the Sex Pistols's attempts to break the mold were not quite so random and anarchic as their progenitors would have us believe.

Transforming Communities

As members of groups, our creative behavior and evaluations of others' innovations reflect a desire to extend the values of those groups and to challenge the values of outsiders. To be celebrated rather than vilified, innovators need to know the norms they are departing from. Eventually they also need an audience willing to embrace the new ways of seeing or behaving made possible by their work. To meet with success, therefore, creative endeavors must transform communities. These newly created audiences then drive the cultural change that novel endeavors spark.

Popular thinking on this topic, however, hews closer to Pablo Picasso's. "Disciples be damned," he once said. "It's only the masters that matter. Those who create." Yet as the curators of a major exhibition at London's National Gallery noted in 2009, Picasso's own work owed much to earlier modes of painting that he eventually rejected, and without admirers his work would have had little influence on society. His work was therefore not about laboring on his own to create everything anew. Rather as Welsh painter Osi Rhys Osmond put it in a review of the exhibition, it was a collaborative exercise in "reinventing the familiar."

We should still study and celebrate the creative genius of individuals. Nevertheless, we need to recognize that the psychology of creativity also involves the groups in which creators develop their work, whose boundaries they seek to extend and through which they have their sway. "I did it my way" may be an appealing anthem for great creators, but as with Frank Sinatra, their success generally also requires promoters, producers and an approving public. M

Even radical efforts to depart from the mainstream, such as those promulgated by punk rock band the Sex Pistols (*right*), get much of their momentum from the culture they reject.

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Fit Body, Fit Mind?

BY CHRISTOPHER HERTZOG, ARTHUR F. KRAMER, ROBERT S. WILSON AND ULMAN LINDENBERGER

As everybody knows, if you do not work out, your muscles get flaccid. What most people don't realize, however, is that your brain also stays in better shape when you exercise. And not just challenging your noggin by, for example, learning a new language, doing difficult crosswords or taking on other intellectually stimulating tasks. As researchers are finding, *physical* exercise is critical to vigorous mental health, too.

Surprised? Although the idea of exercising cognitive machinery by performing mentally demanding activities—popularly termed the "use it or lose it" hypothesis—is better known, a review of dozens of studies shows

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HOW CAN YOU STAY SHARP INTO OLD AGE?

IT IS NOT JUST A MATTER OF WINNING THE GENETIC LOTTERY. WHAT YOU DO CAN MAKE A DIFFERENCE

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AT ONE TIME, THE ACCEPTED STEREOTYPE WAS THAT "OLD DOGS CAN'T LEARN NEW TRICKS." SCIENCE HAS PROVED THAT THIS DICTUM MUST BE DISCARDED.

Stimulating challenges such as puzzles help us keep our edge.

K-P WOLF *Getty Images*

that maintaining a mental edge requires more than that. Other things you do—including participating in activities that make you think, getting regular exercise, staying socially engaged and even having a positive attitude—have a meaningful influence on how effective your cognitive functioning will be in old age.

Further, the older brain is more plastic than is commonly known. At one time, the accepted stereotype was that "old dogs can't learn new tricks." Science has proved that this dictum must be discarded. Although older adults generally learn new pursuits more slowly than younger people do and cannot reach the peaks of expertise in a given field that they might have achieved if they had started in their youth, they nonetheless can improve their cognitive performance through effort—forestalling some of the declines in cognition that come with advancing age. As John Adams, one of the founding fathers and the second U.S. president, put it: "Old minds are like old horses; you must exercise them if you wish to keep them in working order."

The news comes at a propitious time. The proportion of older adults in the U.S. and in other industrial nations continues to grow: in 1900, 4.1 percent of U.S. citizens were older than 65, but by 2000 that amount had jumped to 12.6 percent; by 2030, 20 percent of us will be in that category. From a societal point of view, prolonging independent functioning is both a desirable goal in itself and a way of deferring costs of long-term care. For individuals, maintaining optimal cognitive functioning is worthwhile simply because it promises to enhance quality of life through the years.

Mental Training

How to keep minds keen over an entire life span is a question philosophers have mulled since the ear-

FAST FACTS
AGING AND THE BRAIN

1. We are used to thinking of intelligence as largely a matter of genetic inheritance, but that is not the whole picture. What we do affects our mental well-being: staying physically and mentally active helps us stay sharp as we age.
2. Nevertheless, our personal efforts to bolster cognitive enhancement cannot forestall all declines in our cognitive performance.
3. What is especially surprising is the powerful link between physical activity and mental acuity. Staying fit helps us keep cognition more robust as well.

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liest writings on record. As Roman orator Cicero put it: "It is exercise alone that supports the spirits, and keeps the mind in vigor." Modern research in this field began in the 1970s and 1980s, with studies that demonstrated that healthy older adults can improve performance to a greater extent than had been previously assumed. The earlier research did not fully address certain questions, such as how long adults could retain the new skills they had acquired through training, whether those specifically developed skills would also positively influence other areas of cognition needed in everyday life, and whether the studies done with small numbers of subjects would be broadly applicable.

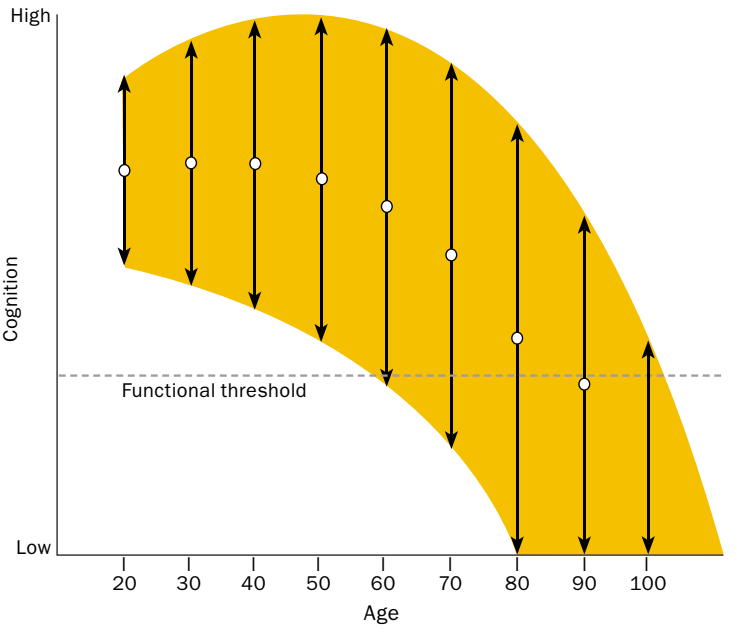
Cognitive training can lead to substantial benefits for older adults on the tasks trained, and some of these benefits are maintained over time and may transfer to other tasks. Toward the end of the 20th century the National Institute on Aging funded a consortium of researchers to conduct a large-scale training study in a sample of older Americans. In 2002 psychologist Karlene Ball of the University of Alabama at Birmingham and her colleagues published initial results on more than 2,500 individuals older than 65 who had received about 10 sessions of cognitive training. Participants were randomly assigned either to a cognitive-process training group to learn how to excel in one of three areas—memory, reasoning or visual search—or to a control group of subjects who did not receive training. At a follow-up two years later, the team randomly selected a set of the initial participants for booster training prior to evaluation. The results showed strong training-effect sizes in each group as compared with controls. In retests five years later, measurable training benefits were still present.

More impressive, however, are recent training studies that focus on what psychologists call working memory and executive functions—how a person plans a strategic approach to a task, controls what is attended to, and how he or she manages the mind in the process. Psychologist Chandramallika Basak, then at the University of Illinois, and her colleagues showed that training in a real-time strategy video game that demands planning and executive control not only improved gaming performance but also enhanced performance on other tasks measuring aspects of executive control.

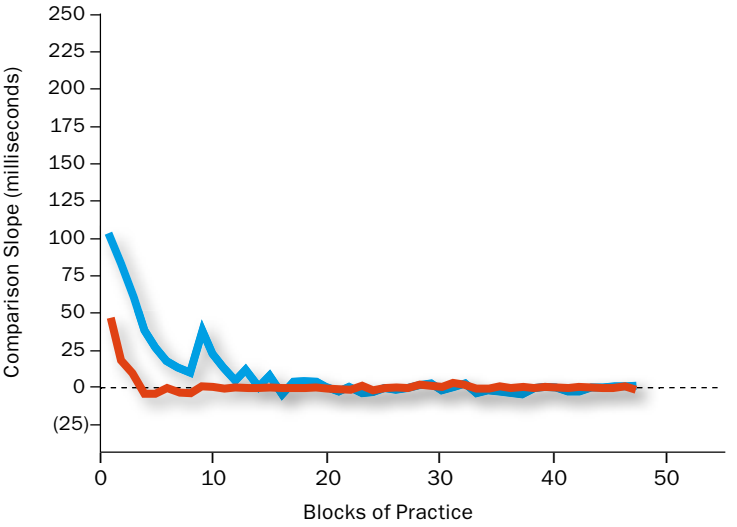
Some studies have also increased the amount of practice provided. For instance, Florian Schmiedek and one of us (Lindenberger) of the Max Planck Institute for Human Development in Berlin and Martin Lövdén of the Karolinska Institute in Stockholm asked 101 younger and 103 older adults to practice

Capabilities over Time

An individual's cognitive function can vary from maturity into old age. Although good habits can promote sound thinking within a given range (*top graph*), we cannot completely halt the effects of aging (*bottom graph*).



Everyone experiences cognitive decline over a lifetime, but exercising the mind and body can help individuals stay above the middle (*white dots*) of the cognitive range (*shaded area*) and remain functional even beyond age 90.



In one study of practice benefits, older adults (mean age 72, *blue*) were slower than younger adults (mean age 21, *red*) to search memory (comparison slope, *vertical axis*) to verify whether a word was one of a set they had committed to memory a short time earlier. But with enough practice, they could speedily identify target words without needing to search for them, producing zero slopes such as those produced by younger people.

SCIENTIFIC AMERICAN MIND; SOURCE FOR TOP GRAPH: "ENRICHMENT EFFECTS ON ADULT COGNITIVE DEVELOPMENT: CAN THE FUNCTIONAL CAPACITY OF OLDER ADULTS BE PRESERVED AND ENHANCED?" BY C. HERTZOG ET AL., IN *PSYCHOLOGICAL SCIENCE IN THE PUBLIC INTEREST*, VOL. 9, NO. 1; OCTOBER 2008, © 2009 ASSOCIATION FOR PSYCHOLOGICAL SCIENCE; SOURCE FOR BOTTOM GRAPH: "AGING AND INDIVIDUAL DIFFERENCES IN THE DEVELOPMENT OF SKILLED MEMORY SEARCH PERFORMANCE," BY C. HERTZOG ET AL., IN *PSYCHOLOGY AND AGING*, VOL. 11, NO. 3; 1996

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12 different tasks for 100 days. Each of the tasks belonged to one of three different sets of cognitive skills—working memory, episodic memory and perceptual speed. Both younger and older adults showed general improvements in working memory. Younger adults also broadly improved in memory and reasoning and maintained their gains in reasoning over a period of two years.

You do not have to have specialized training, however, to achieve cognitive gains or ward off cognitive decline. Everyday activities such as reading can help. We reviewed evidence on activity-related cognitive enrichment in more than a dozen studies. In 2003 one of us (Wilson) and his colleagues at Rush University Medical Center in Chicago recruited more than 4,000 elderly people from a geographically defined community and rated their frequency of participation in seven cognitive activities (for instance, reading magazines). At three-year intervals for a mean of nearly six years, participants completed an in-home interview that included brief tests of cognitive function. More frequent cognitive activity at the outset was associated with reduced rate of cognitive decline over time. But not all studies of staying cognitively active have found such benefits.

Getting Physical

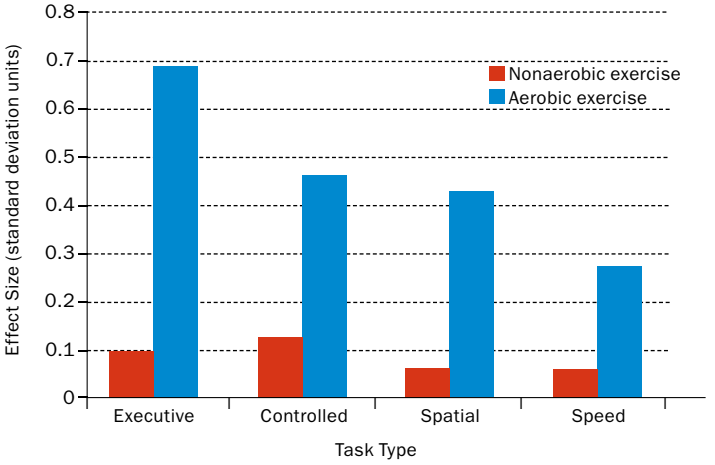
Over the past decades several studies have underscored the link between physical activity and cognition. For instance, in a study published in 2001 neuropsychiatrist Kristine Yaffe of the University of California, San Francisco, and her colleagues recruited 5,925 women older than 65 at four different medical centers across the U.S. The participants were all free of any physical disability that would limit their ability to walk or pursue other physical activities. The volunteers were also screened to ensure that they did not have a cognitive impairment. The researchers then assessed their physical activity by asking the women how many city blocks they walked and how many flights of stairs they climbed daily and gave them a questionnaire to fill out about their levels of participation in 33 different physical activities. After six to eight years, the researchers assessed the women's level of cognitive function. The most active women had a 30 percent lower risk of cognitive decline. Interestingly, walking distance was related to cognition, but walking speed was not. It seems that even moderate levels of physical activity can serve to limit declines in cognition.

AFTER SIX TO EIGHT YEARS, THEY ASSESSED THE WOMEN'S LEVEL OF COGNITIVE FUNCTION. THE MOST ACTIVE HAD A 30 PERCENT LOWER RISK OF DECLINE.

Moderate movement is good, but toning your circulatory system with aerobic exercise may be the real key to brain fitness. In a 1995 study of 1,192 healthy 70- to 79-year-olds, cognitive neuroscientist Marilyn Albert of Johns Hopkins University and her colleagues measured cognition with a battery of tasks that took approximately 30 minutes to complete and included tests of language, verbal memory, nonverbal memory, conceptualization and visuospatial ability. They found that the best predictors of cognitive change over a two-year period included strenuous activity and peak pulmonary expiratory flow rate. In an investigation published in 2004 epidemiologist Jennifer Weuve, then at Harvard University, and her colleagues also examined the relation between physical activity and cog-

The Power of Walking

Older adults who participated in aerobic exercise (walking) outperformed those in programs for stretching and toning (controls) in cognitive task areas: executive (related to planning and multitasking), controlled (effortful processes in response to novel situations), spatial (dealing with spatial information in perception or memory) and speed.



SOURCE: "FITNESS EFFECTS ON THE COGNITIVE FUNCTION OF OLDER ADULTS: A META-ANALYTIC STUDY," BY STANLEY J. COLCOMBE AND ARTHUR F. KRAMER, IN *PSYCHOLOGICAL SCIENCE*, VOL. 14, NO. 2, MARCH 2003

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Physical activity bolsters memory and thwarts dementia.

CIRCLESTOCK *Corbis*

nitive change over a two-year period in 16,466 nurses older than 70. Participants logged how much time they spent per week in a variety of physical activities (running, jogging, walking, hiking, racket sports, swimming, bicycling, aerobic dance) over the past year and provided self-reports of walking pace in minutes per mile. Weuve's group observed a significant relation between energy expended in physical activities and cognition, across a large set of cognitive measures.

The research that we have described thus far has examined mental performance over relatively short periods—just several years. A few studies have begun to look at what happens over longer timescales. In 2005 Suvi Rovio, now at the University of Turku in Finland, and her colleagues examined the relation between physical activity at middle age and risk of dementia an average of 21 years later, when the cohort was between 65 and 79 years of age. Subjects indicated how often they participated in leisure-time physical activities that lasted at least 20 to 30 minutes and caused breathlessness and sweating. Conducting such activity at midlife at least twice a week was associated with a reduced risk of dementia in later life. Indeed, participants in the more active group had 52 percent lower odds of having dementia than the more sedentary group did.

In 2010 Kirk Erickson and his colleagues at the University of Pittsburgh extended previous research examining the relation between physical activity, cognition and dementia by assessing self-reported physical activity alongside measures of regional brain volume. They reported an association between walking and retention of brain volume, which in turn predicted a reduced risk of dementia in 299 older adults over a period of 13 years. Interestingly, it is not just aerobic forms of physical activity (such as walking, jogging, swimming and bicycling) that have been associated with improvements in cognition. Teresa Liu-Ambrose, a professor of physical therapy at the University of British Columbia, reported in 2010 that resistance

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Socializing—and even a positive attitude—helps your brain stay healthier.

exercise, over a one-year period, improved aspects of executive control in older women.

Mind-Body Connection

It makes sense that training or participation in mentally stimulating activities would help cognition, but it is perhaps less immediately obvious why physical activity would have such an effect. Consider the increasingly well-documented link between physical activity and disease. A plethora of studies have examined the health benefits of exercise and a nonsedentary lifestyle for prevention of disease. For example, we now know that physical activity reduces the risk of cardiovascular-related death, type 2 diabetes, colon and breast cancer, and osteoporosis. On the other hand, cardiovascular disease, diabetes and cancer have been associated with compromised cognition. Therefore, you might expect that increased physical activity and exercise would maintain cognition by reducing risk of diseases associated with cognitive decline.

In a study published in 2006 psychologist Stanley J. Colcombe, then at the University of Illinois, and his colleagues examined the influence of fitness training on potential changes in brain structure. The six-month trial included 59 healthy but sedentary community-dwelling volunteers, age 60 to 79. Brain scans after fitness training showed that even relatively short exercise interventions can begin to restore some of the losses in brain volume associated with normal aging. In 2011 Erickson and his colleagues reported on work done at the University of Illinois, which showed that one year of walking, an hour a day for three days a week, increased the volume of the hippocampus in older adults. The hippocampus supports important aspects of memory such as associating an individual's face with her name and discussions that you might have had with her.

Supporting these findings, a large body of nonhuman animal research has demonstrated a number of changes in brain structure and function after animals are exposed to enriched, or complex, environments. Enriched environments usually include running wheels, a multitude of toys and objects to climb that are changed frequently, and animal companions. Exposure to such environments yields several physiological benefits. First, it increases the formation of new dendrite branches and synapses—the areas of neural cells that receive and send communication signals. It also increases the number of glial cells, which support the health of neurons, and expands the brain's oxygen-supplying capillary network. Enriched environments foster the development of new neurons and create a cascade of molecular and neurochemical changes, such as an increase in neurotrophins—molecules that protect and grow the brain. Finally, physical activity in animals results in improvements in learning and memory.

Doing puzzles and push-ups are helpful for some—but other factors also boost mental fitness. For one, getting involved in social groups both improves cognition in general and seems to help thwart the arrival of dementia. The traditional focus of this research has been on relatively objective measures of social isolation versus connectedness, including the extent to which a person participates in activities that prominently involve social interaction (such as doing

See the *Psychological Science in the Public Interest* article "Enrichment Effects on Adult Cognitive Development: Can the Functional Capacity of Older Adults Be Preserved and Enhanced?" on which this story for *Scientific American* was originally based, at the Association for Psychological Science's Web site: **www.psychologicalscience.org**

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volunteer work), the number of friends and relatives an individual contacts regularly (in other words, the size of a person's social network), and marital status. Findings about the positive aspects of attitudes and beliefs on adult cognition are spottier. In large part, positive beliefs and attitudes may have important indirect effects on cognitive enrichment because of their influence on the kinds of behaviors (for instance, exercise and mentally stimulating activities) that are known to be associated with cognitive enrichment.

More generally, individuals who are optimistic, agreeable, open to new experiences, conscientious, positively motivated and goal-directed are more likely to undergo successful aging, to take advantage of opportunities, to cope effectively with life circumstances, to effectively regulate emotional reactions to events, and to maintain a sense of well-being and life satisfaction in the face of challenge.

POSITIVE ATTITUDES MAY HAVE IMPORTANT EFFECTS ON COGNITIVE ENRICHMENT BECAUSE OF THEIR INFLUENCE ON HEALTHY BEHAVIORS.

And just as maintaining some activity patterns in old age may reduce risk of cognitive decline, the persistence of other patterns of behavior may increase the risk. Chronic psychological distress—resulting from depression, anxiety, and negative emotions such as anger and shame—is associated with a variety of negative outcomes in adulthood, including cognitive decline. The tendency to experience psychological distress is often called neuroticism. Studies have consistently found a higher level of neuroticism to be linked to an increased incidence of Alzheimer's disease and mild cognitive impairment in old age.

Enriching Cognition

Clearly, there is no magic pill that inoculates the individual against cognitive decline in old age. Thus, public policy should follow a health prevention model. Policy leaders might promote intellectual activities that are inherently meaningful for older adults, perhaps as embedded in larger social contexts (for example, the Elderhostel movement or adult continuing education). A critical issue for future research will be to understand how an engaged way of life can be promoted and implemented in midlife, during the working years. Given inevitable conflicts between work demands and time available for other roles (parenting, for one) and activities, it would be useful to know whether work-related activity programs (such as availability and use of physical exercise facilities at or near the workplace) could help foster an enriching lifestyle.

At the same time, the public must be aware that there is still much that is not known about cognitive fitness in old age, as well as some controversy about the magnitude and durability of mental exercise outcomes. People are marketing computer games and other means of exercising the mind, often making strong claims about the effectiveness of expensive products that have not been backed by actual scientific studies. Consumers should look for evidence demonstrating the benefits of such products—particularly with regard to everyday activities such as driving, memory for daily activities and better financial decision making.

The next decades offer much promise for expanding our knowledge about aging and cognition. We may soon discover whether the limits on successful cognitive functioning in old age that were once seen as insurmountable can ultimately be viewed as pessimistic assumptions that focused on observable age-related decline rather than the potential for maximizing human performance through cognitive enrichment. Just as advances in medical science may lead to increased longevity through vehicles such as effective treatments for dementia-causing illnesses, advances in psychological science can make important contributions to improving the quality of life of long-living older adults, in part by empirically demonstrating that attitudes and behaviors can promote cognitive functioning in old age and, more generally, by showing how behavioral interventions can help us all age successfully. M

MORE TO EXPLORE

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WHAT WORKS, WHAT DOESN'T

SOME STUDY TECHNIQUES ACCELERATE LEARNING, WHEREAS OTHERS ARE JUST A WASTE OF TIME—BUT WHICH ONES ARE WHICH? AN UNPRECEDENTED REVIEW MAPS OUT THE BEST PATHWAYS TO FOLLOW

BY JOHN DUNLOSKY, KATHERINE A. RAWSON, ELIZABETH J. MARSH, MITCHELL J. NATHAN AND DANIEL T. WILLINGHAM

ILLUSTRATIONS BY CELIA JOHNSON

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Education generally focuses on what you study, such as algebra, the elements of the periodic table or how to conjugate verbs. But learning *how* to study can be just as important, with lifelong benefits. It can teach you to pick up knowledge faster and more efficiently and allow you to retain information for years rather than days.

Cognitive and educational psychologists have developed and evaluated numerous techniques, ranging from rereading to summarizing to self-testing, for more than 100 years. Some common strategies markedly improve student achievement, whereas others are time-consuming and ineffective. Yet this information is not making its way into the classroom. Teachers today are not being told which learning techniques are supported by experimental evidence, and students are not being taught how to use the ones that work well. In fact, the two study aids that students rely on the most are not effective. One of them may even undermine success.

One potential reason is that the huge amount of research is overwhelming, making it difficult for educators and students to identify the most practical and advantageous ways to study. To meet this challenge, we reviewed more than 700 scientific articles on 10 commonly used learning techniques. We focused on strategies that seem to be easy to use and broadly effective. We also took a closer look at a couple of methods that are very popular with students.

To receive our recommendation, a technique must be useful in a range of learning conditions, such as whether a student works alone or in a group. It must assist learners of various ages, abilities and levels of prior knowledge—and it must have been tested in a classroom or other real-world situation. Learners should be able to use the method to master a variety of subjects, and their performance should benefit no matter what kind of test is used to measure it. The best approaches also result in long-lasting improvements in knowledge and comprehension.

Using these criteria, we identified two clear winners. They produced robust, durable results and were relevant in many situations. Three more are recommended with reservations, and five—including two popular learning aids—are not advised, either because they are useful only in limited circumstances or because not enough evidence supports a higher rating. We encourage researchers to further explore some of the untested techniques, but students and teachers should be cautious about relying on them.

FAST FACTS

RATING THE BEST WAYS TO STUDY

1. Some study methods work in many different situations and across topics, boosting test performance and long-term retention. Learning how to learn can have lifelong benefits.
2. Self-testing and spreading out study sessions—so-called distributed practice—are excellent ways to improve learning. They are efficient, easy to use and effective.
3. Underlining and rereading, two methods that many students use, are ineffective and can be time-consuming.
4. Other learning techniques need further testing and evaluation. In the meantime, students and teachers can put proved study methods to use in classrooms and at home.

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THE GOLD STAR WINNERS

1. SELF-TESTING Quizzing Yourself Gets High Marks

HOW IT WORKS: Unlike a test that evaluates knowledge, practice tests are done by students on their own, outside of class. Methods might include using flash cards (physical or digital) to test recall or answering the sample questions at the end of a textbook chapter. Although most students prefer to take as few tests as possible, hundreds of experiments show that self-testing improves learning and retention.

In one study, undergraduates were asked to memorize word pairs, half of which were then included on a recall test. One week later the students remembered 35 percent of the word pairs they had been tested on, compared with only 4 percent of those they had not. In another demonstration, undergraduates were presented with Swahili-English word pairs, followed by either practice testing or review. Recall for items they had been repeatedly tested on was 80 percent, compared with only 36 percent for items they had restudied. One theory is that practice testing triggers a mental search of long-term memory that activates related information, forming multiple memory pathways that make the information easier to access.

WHEN DOES IT WORK? Anyone from preschoolers to fourth-year medical students to middle-aged adults can benefit from practice testing. It can be used for all kinds of factual information, including learning words in foreign languages, making spelling lists and memorizing the parts of flowers. It even improves retention for people with Alzheimer's disease. Short, frequent exams are most effective, especially when test takers receive feedback on the correct answers.

Practice testing works even when its format is different from that of the real test. The beneficial effects may last for months to years—great news, given that durable learning is so important.

IS IT PRACTICAL? Yes. It requires modest amounts of time and little to no training.

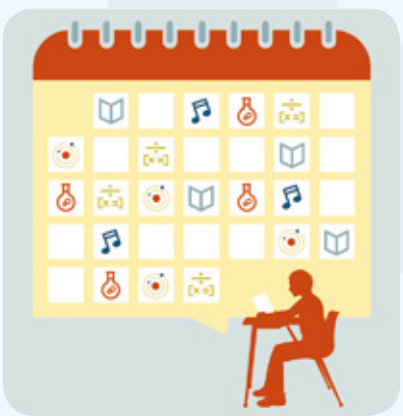
HOW CAN I DO IT? Students can self-test with flash cards or by using the Cornell system: during in-class note taking, make a column on one edge of the page where you enter key terms or questions. You can test yourself later by covering the notes and answering the questions (or explaining the keywords) on the other side.

RATING: High utility. Practice testing works across an impressive range of formats, content, learner ages and retention intervals.

WE REVIEWED MORE THAN 700 SCIENTIFIC ARTICLES ON 10 COMMON LEARNING TECHNIQUES TO IDENTIFY THE MOST ADVANTAGEOUS WAYS TO STUDY.

ISTOCKPHOTO (*star*)

2. DISTRIBUTED PRACTICE For Best Results, Spread Your Study over Time



HOW IT WORKS: Students often "mass" their study—in other words, they cram. But distributing learning over time is much more effective. In one classic experiment, students learned the English equivalents of Spanish words, then reviewed the material in six sessions. One group did the review sessions back to back, another had them one day apart and a third did the reviews 30 days apart. The students in the 30-day group remembered the translations the best. In an analysis of 254 studies involving more than 14,000 par-

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ticipants, students recalled more after spaced study (scoring 47 percent overall) than after massed study (37 percent).

WHEN DOES IT WORK? Children who are as young as age three benefit, as do undergraduates and older adults. Distributed practice is effective for learning foreign vocabulary, word definitions, and even skills such as mathematics, music and surgery.

IS IT PRACTICAL? Yes. Although textbooks usually group problems together by topic, you can intersperse them on your own. You will have to plan ahead and overcome the common student tendency to procrastinate.

HOW CAN I DO IT? Longer intervals are generally more effective. In one study, 30-day delays improved performance more than lags of just one day. In an Internet-based study of trivia learning, peak performance came when sessions were spaced at about 10 to 20 percent of the retention interval. To remember something for one week, learning episodes should be 12 to 24 hours apart; to remember something for five years, they should be spaced six to 12 months apart. Although it may not seem like it, you actually do retain information even during these long intervals, and you quickly relearn what you have forgotten. Long delays between study periods are ideal to retain fundamental concepts that form the basis for advanced knowledge.

RATING: High utility. Distributed practice is effective for learners of different ages studying a wide variety of materials and over long delays. It is easy to do and has been used successfully in a number of real-world classroom studies.

THE RUNNERS-UP

Despite their promise, the following learning techniques fall short, in many cases because not enough evidence has been amassed to support their use. Some techniques, such as elaborative interrogation and self-explanation, have not been evaluated sufficiently in real-world educational contexts. Another emerging method called interleaved practice has just begun to be systematically explored. Nevertheless, these techniques show enough potential for us to recommend their use in the situations described briefly here.

3. ELABORATIVE INTERROGATION Channel Your Inner Four-Year-Old

HOW IT WORKS: Inquisitive by nature, we are always looking for explanations for the world around us. A sizable body of evidence suggests that prompting students to answer "Why?" questions also facilitates learning.

With this technique, called elaborative interrogation, learners produce explanations for facts, such as "Why does it make sense that…?" or "Why is this true?" In one experiment, for example, students read sentences such as "The hungry man got into the car." Participants in an elaborative-interrogation group were asked to explain why, whereas others were provided with an explanation, such as "The hungry man got into the car to go to the restaurant." A third group simply read each sentence. When asked to recall which man performed what action ("Who got in the car?"), the elaborative-interrogation group answered about 72 percent correctly, compared with about 37 percent for the others.

WHEN SHOULD I USE IT? When you are learning factual information—particularly if you already know something about the subject. Its power increases with prior knowledge; German students benefited from elaborative interrogation more when they were learning about German states than about Canadian provinces, for example. It may be that prior knowledge permits students to generate more appropriate explanations for why a fact is true.

PROMPTING STUDENTS TO ANSWER "WHY?" QUESTIONS, CALLED ELABORATIVE INTERROGATION, ALSO FACILITATES LEARNING.

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The effects of this technique appear to be robust across ages, from fourth graders through undergraduates. Elaborative interrogation clearly improves memory for facts, but whether it also might enhance comprehension is less certain, and there is no conclusive information about how long the gains in learning persist.

IS IT PRACTICAL? Yes. It requires minimal training and makes reasonable time demands. In one study, an elaborative-interrogation group required 32 minutes to do a task that took 28 minutes for a reading-only group.

RATING: Moderate utility. The technique works for a broad range of topics but may not be useful for material more complex than a factual list. Benefits for learners without prior knowledge may be limited. More research will be needed to establish whether elaborative interrogation generalizes to various situations and different types of information.

4. SELF-EXPLANATION How Do I Know?

HOW IT WORKS: Students generate explanations of what they learn, reviewing their mental processing with questions such as "What new information does the sentence provide for you?" and "How does it relate to what you already know?" Similar to elaborative interrogation, self-explanation may help integrate new information with prior knowledge.

WHEN SHOULD I USE IT? It benefits kindergartners to college students and helps in solving math problems and logical reasoning puzzles, learning from narrative texts and even mastering endgame strategies in chess. In younger children, self-explanation can help with basic ideas such as learning numbers or patterns. The technique improves memory, comprehension and problem solving—an impressive range of outcomes. Most studies, however, have measured effects within only a few minutes, and it is not known whether the technique is more lasting in people of high or low knowledge.

IS IT PRACTICAL? Unclear. On the one hand, most students need minimal instruction and little to no practice, although one test of ninth graders showed that students without training tended to paraphrase rather than generate explanations. On the other, a few studies report that this technique is time-consuming, increasing time demands by 30 to 100 percent.

RATING: Moderate utility. Self-explanation works across different subjects and an impressive age range. Further research must establish whether these effects are durable and whether the time demands make it worthwhile.

5. INTERLEAVED PRACTICE Mixing Apples and Oranges

HOW IT WORKS: Students tend to study in blocks, finishing one topic or type of problem before moving on to the next. But recent research has shown benefits for interleaved practice, in which students alternate a variety of types of information or problems. In one study, for example, college students learned to compute the volumes of four different geometric shapes. In a so-called blocked-practice condition, they finished all the problems for one shape before moving on to the next. In interleaved practice, the problems were intermixed. When tested

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What Doesn't Work

These techniques were rated as low utility because they are inefficient, ineffective or beneficial only for certain types of learning and for short periods of retention. Most students report rereading and highlighting, yet these techniques do not consistently boost performance, and they distract students from more productive strategies. Other methods mentioned below are just too time-consuming.

Highlighting

Students commonly report underlining, highlighting or otherwise marking material. It is simple and quick—but it does little to improve performance. In controlled studies, highlighting has failed to help U.S. Air Force basic trainees, children and remedial students, as well as typical undergraduates. Underlining was ineffective regardless of text length and topic, whether it was aerodynamics, ancient Greek schools or Tanzania.

In fact, it may actually hurt performance on some higher-level tasks. One study of education majors found that underlining reduced their ability to draw inferences from a history textbook. It may be that underlining draws attention to individual items rather than to connections across items.

WHAT YOU SHOULD DO INSTEAD: Highlighting or underlining can be useful if it is the beginning of a journey—if the marked information is then turned into flash cards or self-tests. Given that students are very likely to continue to use this popular technique, future research should be aimed at teaching students how to highlight more effectively—which likely means doing it more judiciously (most undergraduates overmark texts) and putting that information to work with a more useful learning technique.

Rereading

In one survey of undergraduates at an elite university, 84 percent said they reread textbooks or notes during study. It requires no training, makes modest demands on time, and has shown some benefits on recall and fill-in-the-blank-style tests.

Yet the evidence is muddy that rereading strengthens comprehension, and whether its effects depend on knowledge level or ability is also woefully underexplored. Most of the benefit of rereading appears to accrue from the second reading, with diminishing returns from additional repetitions. No experimental research has assessed it using materials from actual courses—ironic, given that this strategy is the one most commonly reported by students.

WHAT YOU SHOULD DO INSTEAD: Don't waste your time—in head-to-head comparisons, rereading fares poorly against more active strategies such as elaborative interrogation, self-explanation and practice testing.

Three less commonly used study techniques also fared poorly in our assessment. "Imagery for text learning" needs more evidence before it can be recommended, whereas "summarization" and "keyword mnemonic" appear to be ineffective and time-consuming.

In summarization, students identify a text's main points, excluding unimportant material. Whether it works is difficult to answer, as it has been implemented in many different ways. It is unknown whether summarizing small pieces of a text or large chunks of it works better or whether the length, readability or organization of the material matters.

With keyword mnemonics, imagery is used to enhance memory; for example, a student learning the French word *la dent* ("tooth") might use the similar-sounding English word "dentist" to form a mental image of a dentist holding a large molar. Mnemonics do seem to help with foreign-language vocabulary, word definitions and medical terminology, but the effects have not been shown to endure, and in the end the effort involved in generating keywords may not be an efficient use of time.

Another technique that uses mental pictures is imagery for text learning, in which students are told to create images for every paragraph they read. Research has revealed a patchwork of inconsistent results that have not been shown to last over the long term. Teachers may consider instructing students to attempt using this technique with image-friendly texts, but further demonstrations of its usefulness are necessary.

See the *Psychological Science in the Public Interest* article "Improving Students' Learning with Effective Learning Techniques: Promising Directions from Cognitive and Educational Psychology," on which this story for *Scientific American* was originally based, at the Association for Psychological Science's Web site: **www.psychologicalscience.org**

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one week later, the interleaved practice group was 43 percent more accurate. Interleaving allows students to practice selecting the correct method and encourages them to compare different kinds of problems.

WHEN SHOULD I USE IT? When the types of problems are similar, perhaps because juxtaposing them makes it easier to see what is different about them. Blocked practice—doing all the items from one category in a row—may be more effective when the examples are not very much alike because it highlights what they have in common.

It is possible that interleaved practice benefits only those who are already reasonably competent. Outcomes are also mixed for different types of content. It improves performance on algebra problems and was effective in a study that trained medical students to interpret electrical recordings to diagnose cardiac disorders. Yet two studies of foreign-vocabulary learning showed no effect for interleaved practice. Nevertheless, given how much difficulty many students have in mathematics, it may still be a worthwhile strategy for that subject.

STUDENTS ARE NOT BEING TAUGHT THE BEST STRATEGIES, PERHAPS BECAUSE TEACHERS THEMSELVES ARE NOT SCHOOLED IN THEM.

IS IT PRACTICAL? It seems to be. A motivated student could easily use interleaving without any instruction. Teachers could also use the technique in the classroom: After one kind of problem (or topic) is introduced, practice first focuses on that problem. Once the next kind of problem is introduced, it is mixed in with examples of earlier subjects. It may take a little more time than blocked practice, but such slowing most likely is worthwhile, reflecting cognitive processes that boost performance.

RATING: Moderate utility. Interleaved practice improves learning and retention of mathematical knowledge and boosts other cognitive skills. The literature on interleaved practice is small, however, and in fact includes enough negative results to raise concern. It may be that the technique does not consistently work well, or perhaps it is not always used appropriately—topics for future research.

What We Have Learned

Why don't students use more effective study techniques? It seems they are not being taught the best strategies, perhaps because teachers themselves are not schooled in them. In our survey of six educational-psychology textbooks, only one technique—"keyword mnemonics"—was covered in every book. None offered much guidance on the use, effectiveness or limitations of different ways of studying.

A second problem may be that in the educational system, the emphasis is on teaching students critical-thinking skills and content. Less time is spent on teaching them how to learn. The result can be that students who do well in their early years, when learning is closely supervised, may struggle once they are expected to regulate their own learning in high school or college.

Some questions, such as the best age for students to start using a technique and how often they will need to be retrained or reminded, still require further research. But even now teachers can incorporate the most successful approaches into lesson plans so that students can adopt them on their own. For instance, when moving to a new section, a teacher can start by asking students to do a practice test that covers important ideas from the previous section and providing immediate feedback. Students can interleave new problems with related ones from preceding units. Teachers can harness distributed practice by reintroducing major concepts during the course of several classes. They can engage students in explanatory questioning by prompting them to consider how the information is new to them or why it might be true.

These learning techniques are no panacea. They benefit only those who are motivated and capable of using them. Nevertheless, we expect that students will make meaningful gains in classroom performance, on achievement tests and during their lifetime. M

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THE AHA! MOMENT

A STEP-BY-STEP GUIDE TO YOUR NEXT CREATIVE BREAKTHROUGH

BY NESSA BRYCE

Take a moment to look at the image on the opposite page. What do you see? Just a neural network? Perhaps you spotted the hidden figure. If so, you have just had a moment of insight. You may have felt a similar jolt when discovering the solution to a math problem, understanding a joke or metaphor, or realizing something unexpected about yourself. These aha! moments occur when your brain spontaneously reinterprets information to reach a novel, nonobvious conclusion.

I painted *Neurons* a few years ago for an art exhibit. I had designed the piece to portray the idea that our brain's neural networks make us who we are. It was only after joining psychologist James T. Enns's vision laboratory at the University of British Columbia in 2013 that I had my own abrupt realization: I recognized how my art could inform science. Using this piece, along with other hidden-object images, I investigated how an individual's focus and attention change when experiencing an unexpected revelation.

For centuries creative individuals have described their sudden breakthroughs, instances when they recombine information in a new and useful way. Scientists view these flashes of insight as markers of the creative process—and observing them in the laboratory elucidates what happens in the brain during problem solving.

ILLUSTRATIONS BY COLIN HAYES

PAINTING BY NESSA BRYCE

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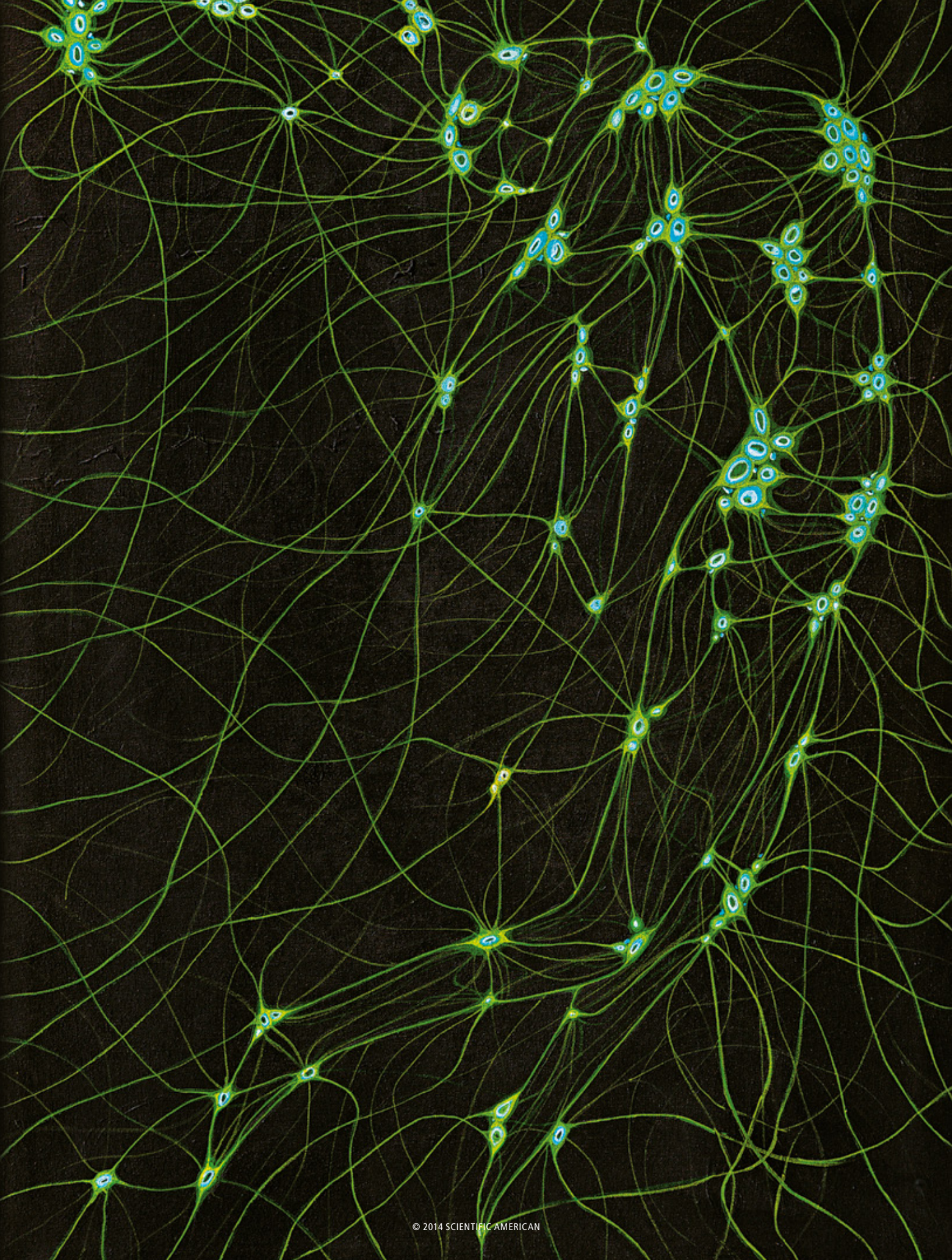

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"A story is emerging about all the factors that lead up to an insight," says cognitive psychologist John Kounios, who studies creativity at Drexel University.

What researchers are finding is that the contemporary science of creativity largely bolsters an almost century-old theory. In 1926 political scientist Graham Wallas defined the creative process as four distinct stages: preparation, incubation, illumination and verification. Since then, scientists have broken some of his stages into substages to reveal distinct cognitive processes. For example, preparation now consists of two parts, one involving general learning and the other more focused on skill building. "These stages really seem to be universal, whether you are a scientist, artist, writer or musician," says Harvard University psychologist Shelley Carson, who has interviewed more than 1,000 creative individuals for her research. And creativity is not restricted to a subset of highly talented artists and thinkers, Carson says. These innovative individuals have a distinct style of thinking, and breaking down their approach can allow anyone to re-create the process. Brain research has revealed that we can all get closer to achieving that magical spark of insight with the help of a few simple techniques.

STAGE 1 EXPLORE

Roughly speaking, people solve problems in one of two ways: they either tend to rely on moments of insight, or they prefer to approach them analytically. Answering questions with analysis involves finding solutions through deliberate, methodical trial and error, whereas insight is perceived as an abrupt epiphany. Both methods are useful, but insight is typically seen as the best option for "out of the box" solutions.

In 2008 Kounios and his colleagues monitored the brain activity of 26 study participants using electroencephalography (EEG) while they sat quietly in a room. After recording these electrical signals, the researchers asked the participants to try to solve 180 anagram problems, which involved reorganizing a word, such as "west," to form another word, "stew." Subjects also reported whether they had used an insightful or analytical approach to solve each problem.

Kounios found that the brain activity of people who used insight differed significantly from that of people who preferred the analytical approach. Before they even began solving problems, most members of the insight group exhibited less activity in the occipital lobe, a region involved in visual processing, compared with the analytical set.

Specifically, the brains in the insight group showed less activity in the so-called alpha-wave range, which reflects neural inhibition, and the beta-1-wave range, which is linked with selective visual attention. In other words, these findings suggest that people who rely on insight tend to experience diffuse visual attention when not actively engaged in a task.

This study, along with Carson's reports from highly creative individuals, suggests that to prime your brain for creativity, you should first wander the world with an open mind. "Gathering a broad base of knowledge is the first stage of the creative process, which usually comes naturally to people through intellectual curiosity," Carson says. Another way to break your thought habits is by asking questions such as "How can I do this differently?" and by stepping outside your comfort zone. A poet with writer's block, for example, might be advised to take up a new hobby such as scuba diving or dance lessons. Neuroscientist-turned-artist Greg Dunn discovered an entirely different way to depict the brain when he began studying Sumi-e art, an Asian style of painting. His experimentation with the style's free-flowing ink led to a simple yet elegant new method for painting neurons.

FAST FACTS

STROKE OF GENIUS

1. Psychologists study the moment of insight, or the abrupt realization of a new solution, as a marker of the creative process.
2. Researchers have broken down the discovery of insightful solutions into stages, including preparation, incubation, illumination and verification.
3. Recognizing the distinct cognitive processes underlying each stage can help everyone use an insightful approach to find innovative solutions.

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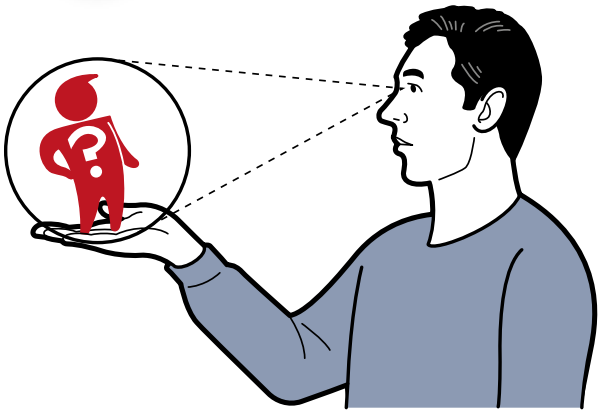
STAGE 2 FOCUS



Psychologist Dean Keith Simonton of the University of California, Davis, has linked creativity with the acquisition of expertise [see "The Science of Genius," by Dean Keith Simonton, on page 4]. In 2000 Simonton compared the cumulative years of experience of 59 opera composers with their aesthetic success. He measured aesthetic achievement in eight different ways—tallying the number of times an opera was recorded and performed in major opera houses, for example, as well as the number of pages devoted to the work in opera histories.

Simonton found that a composer's years of musical experience were a powerful predictor of an opera's acclaim. He also found that if the composer had already created a number of other works within the same genre, this would actually hurt the opera's critical reception and legacy. In other words, solutions to great problems demand practice, skill and study, yet creative solutions occur when someone applies their experience to new domains.

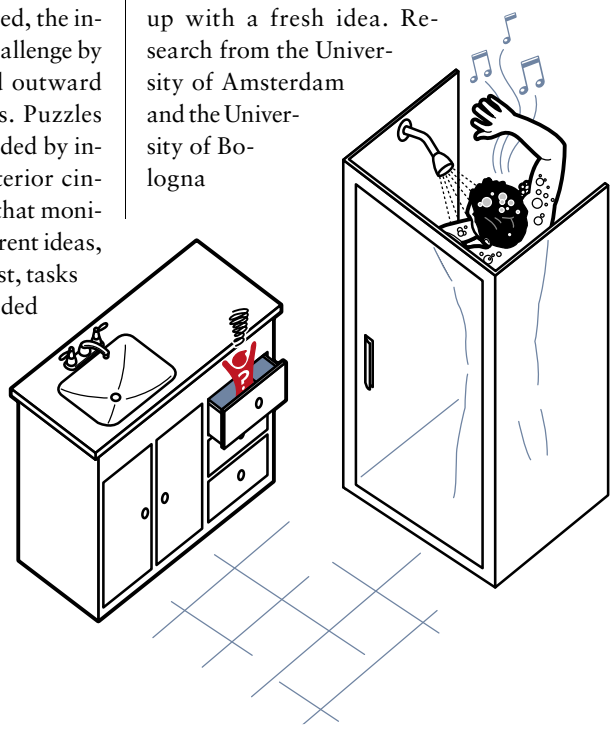
Whether you are proving Fermat's last theorem or planning a birthday party, finding novel solutions involves a little advance research. How much preparation you need will vary, but the more you know about a problem, the better equipped you are to solve it. Some of the most creative minds in history were masters of their respective fields. Given that these people spent large amounts of time immersed in their studies, one of the best ways to maximize your creativity is to find an area in which you would like to develop expertise. Then follow that passion.

STAGE 3 INCUBATE

Once you have immersed yourself in a problem, the best way to come up with a creative solution is to stop consciously thinking about it. In 2006 Kounios and his colleagues used functional magnetic resonance imaging (fMRI) to record the brain activity of 44 men and women as they solved 185 remote-association problems. These word puzzles require finding a single word that can turn three seemingly unrelated words into familiar compound phrases; for example, the solution to "foam," "deep" and "salt" is "sea." After finding an answer, the subjects reported whether they had solved the problem using insight or analysis.

Kounios found that in the two seconds before a problem appeared, the insight users prepared for the challenge by shifting from their scattered outward attention to an inward focus. Puzzles solved insightfully were preceded by increased activation in the anterior cingulate cortex, a brain region that monitors internal attention to different ideas, among other things. In contrast, tasks solved analytically were preceded by significant activation in the occipital lobe, which, as mentioned before, handles visual processing. This increase indicates that the analytical solvers concentrated more on what they were looking at.

Other studies suggest that activities that shift your focus inward, such as meditation, might help you come up with a fresh idea. Research from the University of Amsterdam and the University of Bologna



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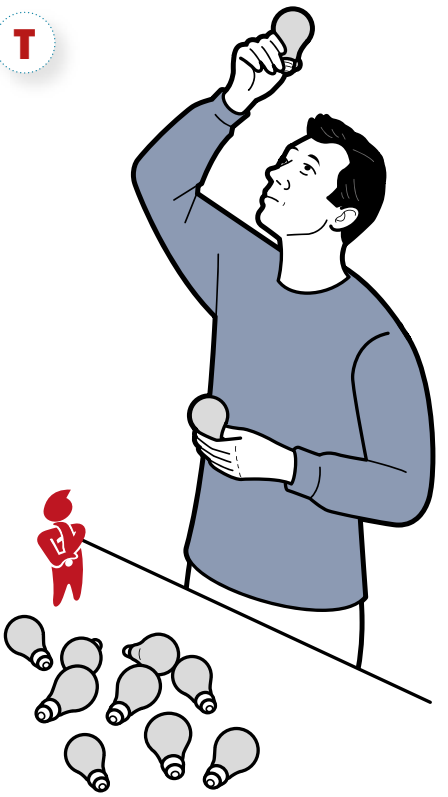
in Italy has demonstrated that sleeping on a problem or stepping away from it and then immersing yourself in an alternative activity can help you unconsciously cultivate creative solutions.

Taken together, the findings reveal a benefit to forcing your brain to shift gears or look within. One reason might be that your attention can then be captured by a surprising solution your unconscious mind has been ruminating on. So take a nap or try your hand at something new.

History is replete with examples of creative individuals who describe being hit with inspiration when daydreaming or attending to a different task. Writer Robert Louis Stevenson and musician Paul McCartney, for instance, used dreams as starting points for new works. Many day-to-day problems can be solved this way, which explains why so many people recall stumbling on ideas while taking a shower, driving to work or simply walking down the road.

STAGE 4 INSIGHT



When insight hits, certain changes happen in the brain. Psychologist Mark Beeman of Northwestern University led a study in 2004 that measured people's brain activity with fMRI and EEG during the moment of insight. As in Kounios's studies, participants tackled remote-association problems and then indicated if they had cracked the problem using insight. The results showed significantly increased activity in the anterior superior temporal gyrus of the right hemisphere at the critical moment when the solution appeared, in comparison to problem solvers who did not experience such an aha moment. This gyrus is a prominent ridge on the cortex of the right hemisphere and plays a fundamental role in recognizing distant connections between words.

The activity surge in the right but not the left lobe may also be meaningful. According to the researchers, there are areas in the right side of your brain that interpret information more loosely than areas in the left side. This means that the information is less tightly defined, allowing you to access other concepts more readily, which is a key component of creativity. Both hemispheres are working all the time, but parts of your right hemisphere might loosely define a cat as a mammal, making it easy to see how a cat relates to, say, an elephant. Parts of your left hemisphere, however, might describe a cat as a small, carnivorous mammal with soft fur, a short snout and retractile claws—something very different from an elephant.

Research has suggested that you can tip the scales toward a looser style of understanding by describing objects or issues in unusual ways. For example, by thinking of a hanger as a long, twisted wire instead of as a metallic instrument for hanging coats, you might discover other uses for it. Try this technique every so often as you are actively working to solve your problem. It might help prime your brain to forge connections between distant concepts.

The moment of insight is also accompanied by a burst of alpha activity in the visual cortex, according to Beeman's study. Alpha activity, as mentioned earlier, inhibits neuron firing, meaning that during a breakthrough, your brain is less involved in processing visual information—perhaps because visual stimuli can be distracting. These findings suggest that you could help your brain discover an insight simply by closing your eyes.

Probably the most famous moment of insight in history is Archimedes' "Eureka!" Legend has it that the ancient Greek mathematician had been challenged to figure out whether a crown that King Hiero II of Syracuse had commissioned was made out of solid gold. Archimedes was preparing a bath when he discovered how to measure an object's volume, and thus its density, after noticing the displacement of water as he climbed into the tub. Although the story may be apocryphal, it has gone down in history in part because it illustrates perfectly how insight strikes.

FLASHES OF INSIGHT ARE MARKERS OF THE CREATIVE PROCESS AND MAY HELP ELUCIDATE WHAT HAPPENS IN THE BRAIN DURING CREATIVE PROBLEM SOLVING.

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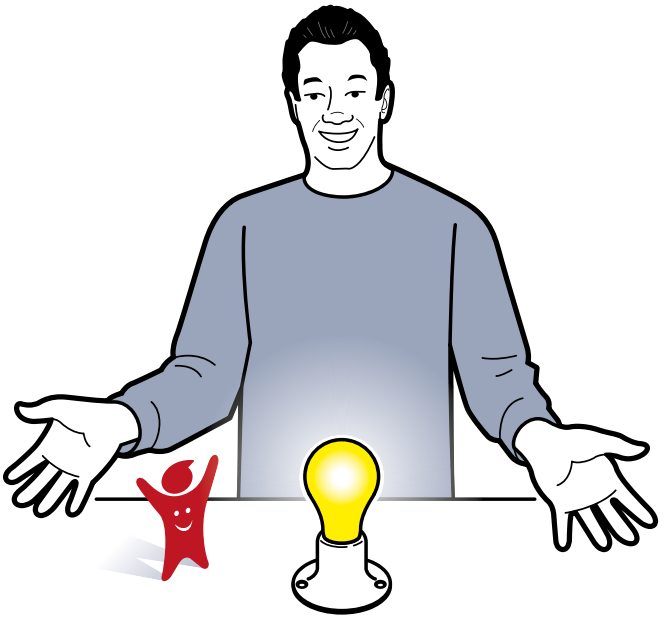
STAGE 5 FOLLOW-THROUGH



Once you have had a moment of insight, you might find yourself feeling elated. A 2013 study by Tufts University researcher Tad Brunyé showed that subjects who came up with broad associations between words, such as associating "pipe" with "flute" rather than with "smoke," experienced a boost in mood. Take advantage of the positive mood to check whether your solution works. "When you have an insight, it comes with a lot of conviction," Carson says. "So you really have to be objective and evaluate that idea."

Melissa Ellamil, a cognitive neuroscientist at the University of British Columbia, led a study in 2011 that uncovered the brain processing involved in the evaluation, as opposed to generation, of creative ideas. Ellamil asked 15 art students to produce illustrations for a book while lying in an fMRI scanner. In six trials, participants produced and evaluated five drawings. Ellamil found that during the evaluation phase, the brain recruited the regions of the temporopolar cortex and prefrontal cortex associated with executive function. These areas support critical thinking and decision making.

This stage is an ideal time to bounce ideas off of trusted friends—their feedback and support could help you determine how well your solution works [see "Creativity Is Collective," by S. Alexander Haslam, Inmaculada Adarves-Yorno and Tom Postmes, on page 26]. Do not be discouraged, though, if your personal eureka is less than perfect. Creative people often describe going through many failures before reaching a successful solution. Those failures help to inform the end result, making them a necessary step in the process. When a student asked chemist and two-time Nobel laureate Linus Pauling how he came up with so many good ideas, he replied, "I have a lot of ideas and throw away the bad ones."

In practice, each stage does not always follow easily from the one before it—many people have to revisit earlier steps several times before hitting on inspiration—but ultimately the process is very rewarding. Creativity not only makes creators happy but also benefits all those who will enjoy their creations.

The joys of an aha moment may even serve a deeper purpose. In 2013 psychologists Claudia Muth and Claus-Christian Carbon of the University of Bamberg in Germany found that participants who identified a hidden face in a picture liked the image more than those who did not identify the face. Muth hypothesizes that insight is rewarding for evolutionary reasons. She says, "It could explain why we explore the world and why we have interest in things that are new."

Being curious and pursuing creative endeavors provides you with the opportunity to discover new interests, explore unfamiliar territory, develop expertise and, crucially, take breaks. In short, working to develop and maximize your creativity serves to enrich your life. As Carson puts it, "Once you realize that you can be creative, it opens up this whole new world." M

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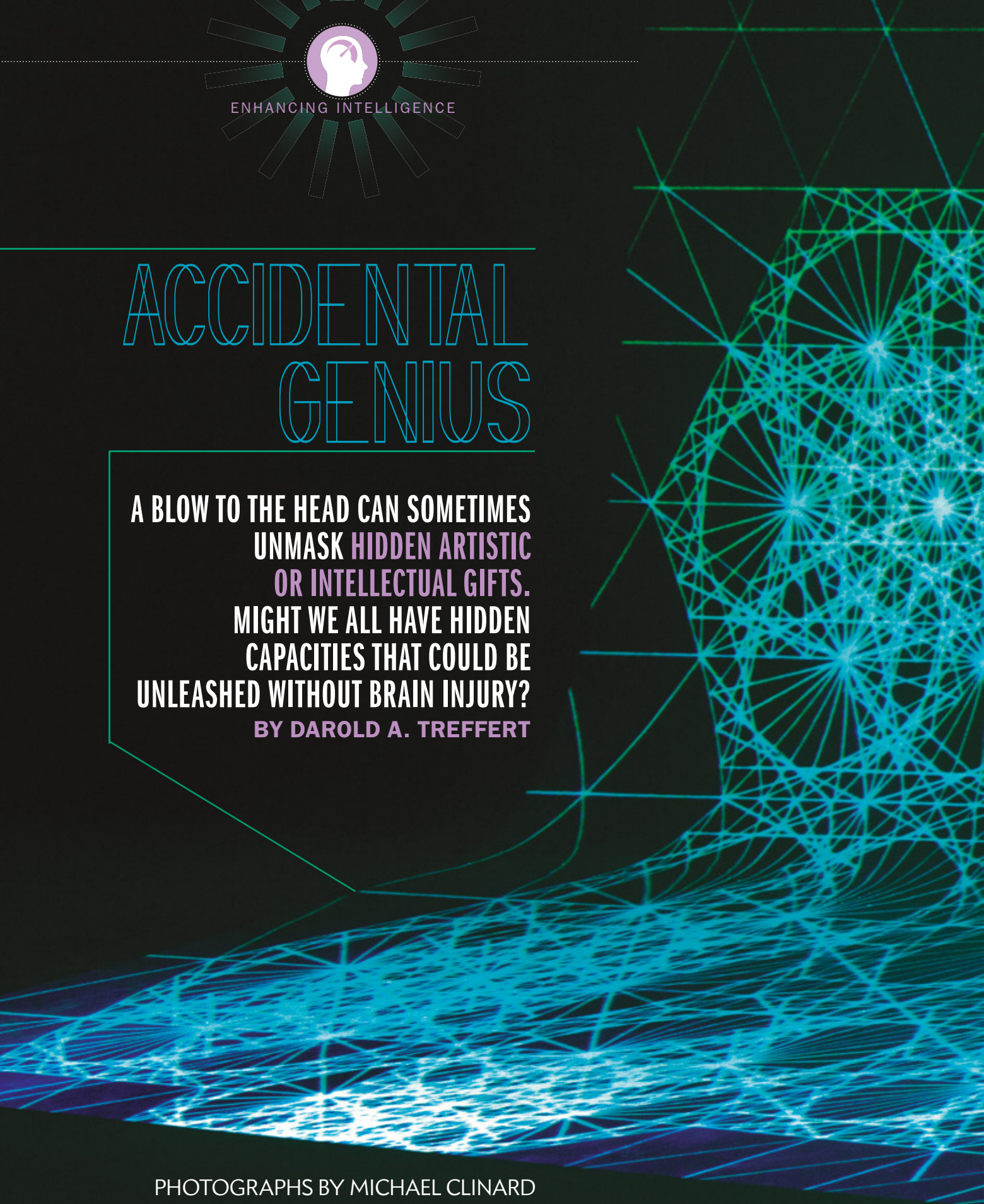
ACCIDENTAL GENIUS

A BLOW TO THE HEAD CAN SOMETIMES UNMASK HIDDEN ARTISTIC OR INTELLECTUAL GIFTS. MIGHT WE ALL HAVE HIDDEN CAPACITIES THAT COULD BE UNLEASHED WITHOUT BRAIN INJURY?

BY DAROLD A. TREFFERT



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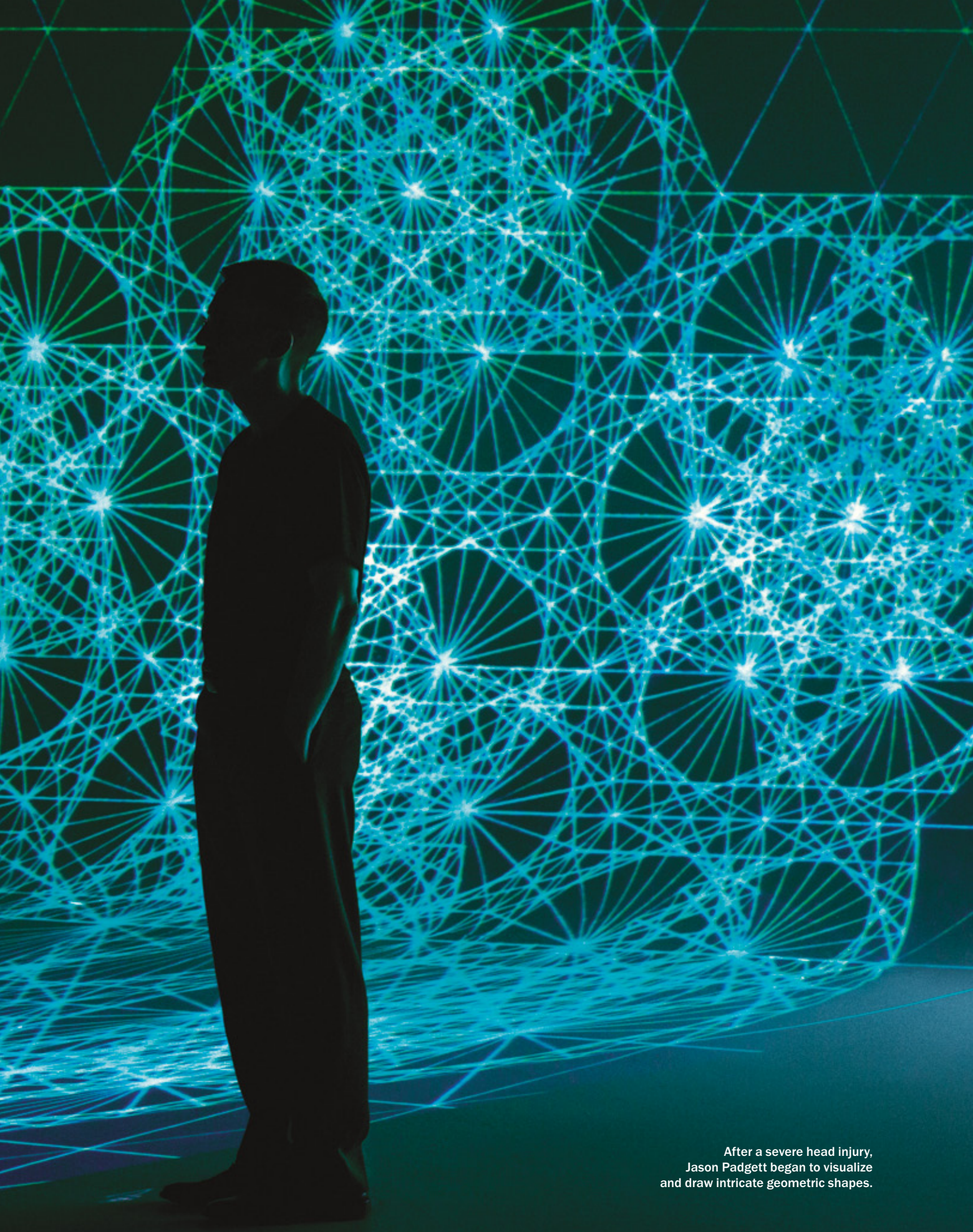

After a severe head injury, Jason Padgett began to visualize and draw intricate geometric shapes.

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A 10-year-old boy, Orlando Serrell, knocked unconscious one day by a baseball, discovered afterward that he could bring to mind the exact day of the week for any date after the accident and could remember the weather for each day since the trauma as well. He could also recall the most minute daily events.

Jason Padgett, the victim of a brutal mugging in 2002 that left him with a severe concussion, soon afterward began to see what he describes simply as "images." He began to sketch them out on paper. When he showed his work to others, he learned that the repeating, self-similar patterns were fractals.

These two people have a remarkable condition known as acquired savant syndrome. In the more familiar savantism—made famous by the 1988 movie *Rain Man*—people are endowed from early in life with extraordinary but narrowly defined musical, artistic, mathematical, memory and mechanical skills that stand in contrast to their marked impairments in language, social interactions and other mental faculties overall. In *Rain Man,* for instance, actor Dustin Hoffman's character, Raymond Babbitt, had stunning mathematical, calendar-calculating and other skills and a massive memory but also showed severe cognitive and behavioral limitations from his underlying autism.

In acquired savant syndrome, in contrast, near-genius levels of artistic or intellectual skills show up after dementia, a severe blow to the head or another insult to the brain. Discovery of this unusual phenomenon raises the possibility that dormant potential in some artistic or intellectual realm—an "inner savant"—resides in each of us. If so, perhaps a way can be found to tap these buried abilities in the absence of disease or injury.

Your Inner Sculptor

I have studied savant syndrome for much of my career. Until the mid-1980s, I assumed it was present from birth—in other words, savant syndrome was a congenital condition. But then I attended the premier exhibition of exceptional sculptures made by Alonzo Clemons. As an infant, Clemons seemed to learn quickly. At about age three, however, a fall resulted in a brain injury, slowing his cognitive development precipitously and leaving him with a serious intellectual disability, including limited vocabulary and speech. But afterward, he developed a spectacular skill for sculpting, using whatever materials were handy—even shortening from the kitchen. With his new talent came a growing fascination with animals. For example, he could look at a photograph of a horse in a magazine and then sculpt a three-dimensional replica in less than half an hour, each muscle and tendon reproduced in exacting detail.

Clemons sparked my interest in acquired savant syndrome, and I looked for reports of it in the medical literature but found only a few instances. In 1923 psychologist Blanche M. Minogue described the appearance of extraordinary musical abilities in a three-year-old following a bout of meningitis. In 1980 T. L. Brink, another psychologist, reported on a nine-year-old boy in whom superior mechanical skills appeared after a bullet wound to his left brain. In his case, he was able to dismantle, reassemble and modify multigear bicycles and invented a punching bag that could simulate the bobbing and weaving of a live opponent.

These sparse reports in the years before 1980 reflected the condition's rarity: a concussion or stroke does not usually enhance cognitive or creative capacity. I then decided to collect descriptions of such cases. By 2010 I had assembled a worldwide registry of 319 known savants, of whom only 32 had the acquired form.

Among the reports entered in my registry was work done by neurologist Bruce Miller, now at the University of California, San Francisco, and his colleagues. In 1996 Miller began compiling the first of 12 cases of people who had a disorder known as frontotemporal dementia (FTD). These elderly patients demonstrated musical or artistic skills for the first time, sometimes at prodigious levels, after their diagnosis. Frontotemporal dementia differs from Alzheimer's dementia in that the degenerative process affects only the frontal lobes and not wider areas of the brain.

FTD often targets the left anterior temporal area of the brain and the orbitofrontal cortex. Both regions normally inhibit activity in the visual system at the back of the brain, which is involved in processing incoming signals from the eyes. The disease seems to foster a newfound artistic sensibility by turning off inhibitory signals from the front of the brain. The releasing of the brakes allows the

FAST FACTS
SAVANT SYNDROME

1. *Rain Man,* the movie starring Dustin Hoffman, brought to popular attention the existence of savant syndrome—in which people with autism display exceptional intellectual or artistic gifts from birth.
2. Acquired savantism is an alternative form of the condition in which a person develops skills such as the ability to paint, play music or do mental calculations after experiencing some form of brain injury.
3. An inner savant may exist in most people if the proper brain circuits are activated or switched off through electrical stimulation technologies or even through focused practice of a particular skill.

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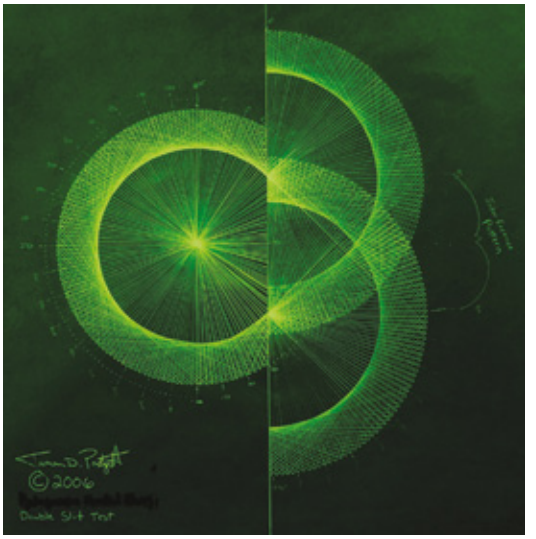

Geometer: Padgett began to produce drawings like the ones at the right when a mugging that caused a concussion unlocked math, physics and artistic capabilities that the college dropout never knew he had.

brain to process sight and sound in new ways. It unleashes artistic or other creative sensibilities even though damage to the frontal lobes may lead to the inappropriate behaviors that characterize the disorder. "FTD is an unexpected window into the artistic process," Miller says.

Further work implies that accidental genius results from diminished activity in some brain areas that is combined with a counterbalancing intensification in others. More specifically, it involves a set of events I call the three Rs that occur after the brain is damaged—most often after the left hemisphere is stricken, similar to what happened with Miller's FTD cases. The process begins with "recruitment," a rise in electrical activity in still intact cortical tissue, often in the right hemisphere. Then the brain circuitry undergoes "rewiring" to establish newly formed connections between regions that were not previously linked. Next comes "release" of dormant capacity as a result of increased access to the newly connected brain areas.

THE AUTHOR

DAROLD A. TREFFERT, a Wisconsin psychiatrist, met his first savant in 1962 and has done research on the syndrome ever since. He served as a consultant for the making of the movie *Rain Man* and maintains a Web page at www.savantsyndrome.com, hosted by the Wisconsin Medical Society.

COURTESY OF JASON PADGETT (*artwork*)

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An experiment done by Richard Chi and Allan Snyder, both then at the Center for the Mind at the University of Sydney, has used a relatively new technology to provide some evidence that these brain changes account for the acquired savant skills. Using transcranial direct-current stimulation (tDCS), these researchers induced savantlike abilities in human volunteers. The technique generates a polarized electric current to diminish activity in a part of the left hemisphere involved with sensory input, memory, language and other brain processes while increasing activity in the right hemisphere (the right anterior temporal lobe).

The investigators then asked study participants to solve the challenging "nine-dot" puzzle either with or without tDCS—a task that requires the creativity to search for a solution in an unconventional way. Participants had to connect three rows of three dots using four straight lines without lifting a pen or retracing lines. None of them could solve it before stimulation, and when 29 subjects were exposed to "sham" stimulation—electrodes emplaced without any current to test for placebo effects—they were still at a loss. With the current switched on, however, some 40 percent—14 of 33 participants—worked their way through the puzzle successfully.

How can a person suddenly perform so much better at the flip of a switch? Because these instant savants—and congenital and acquired savants as well—"know things" innately they were never taught. Clemons, the sculptor, had no formal training in art but knew instinctively how to produce an armature, the frame for the sculpture, to enable his pieces to show horses in motion.

One plausible explanation for the hidden talents that emerge in savant syndrome—whether early in life or induced by injury—is that these reservoirs of skill and knowledge must be inherited in some way. We do not start life with a blank slate that subsequently gets inscribed through education and other life experiences. The brain may come loaded with a set of innate predispositions for processing what it sees or for understanding the "rules" of music, art or mathematics. Savants can tap into that inherited knowledge far better than the average person can.

The Genius Switch

Knowing that these talents can emerge even later in life raises the question of

CASE HISTORIES

The Ultimate Eureka Moments

Acquired savantism has given people the ability to pursue poetry, music and instantaneous mental calculations. A few cases from a registry of savants follow:

The late Tommy McHugh was a 51-year-old builder in Liverpool, England, without any particular interest in poetry or painting. After suffering in 2001 a hemorrhage in the lining of the skull that damaged the frontal area of his brain, he suddenly began to fill notebooks with poems and to spend much of his time painting and sculpting. Physicians attributed this new talent to "relative disinhibition," which frees up the ability to evoke unusual word juxtapositions or imagery. McHugh has had exhibits in the U.K., and his story has been chronicled in a number of television documentaries.

Orlando Serrell, mentioned earlier, who began doing calendar calculations as a boy after being knocked out by a baseball, can determine the day of the week for any day since the injury occurred. He also recalls the weather every day since his injury. Now at 44, the Virginia man is still able to calendar-calculate, but his memory skills have advanced so that he can remember the minutest details of each day's activities—a condition known as hyperthymestic memory. Brain scans at Columbia University Medical Center have confirmed that Serrell engages in unconscious calculating—and his skill is not based on memorizing the calendar.

Derek Amato was a 40-year-old corporate trainer in Colorado with no special interest or skill in music. In 2006 he dove into the shallow end of a swimming pool, sustaining a severe concussion and losing some hearing in one ear. Following his hospital discharge, he was inexplicably drawn to the piano, which he had never touched before. He began to see black-and-white spots that he was able to transpose from his head into notes on the piano. He now makes his living composing, performing and recording.

Tony Cicoria, an orthopedic surgeon from New York, was talking on the telephone in 1994 when he was struck by lightning. Presumed to be in cardiac arrest, he was resuscitated by a nurse who was waiting to use the phone. For a week or two he had some mild memory problems. Those eventually subsided, and he resumed his orthopedic surgery practice full-time with no residual effects from the lightning strike. But one thing had changed. He developed a consuming obsession with classical music. Before the incident, he thought of himself as mainly a "rocker." But his newfound obsession morphed into a desire to play classical music as well. Shortly after his injury, he heard music in a dream. The tune stuck with him, resonating in his head whether he was awake or asleep. Finally, he decided to transcribe the earworm into a 26-page concert piano piece called Fantasia: The Lightning Sonata, op. 1.

Jason Padgett, who developed a passion for math, physics and drawing geometric shapes after he sustained a concussion following the assault mentioned earlier, still runs three futon stores in Washington State. He now calls the injury, mentioned earlier, a "rare gift." Before the mugging, Padgett described himself as being among the "math-averse." Now the former college dropout takes higher-level math courses to fully understand the geometric figures that are his obsession, and he has written a popular book about his experiences. —*D.A.T.*

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whether everyone has the capacity to become a savant—and whether it might be possible to do so without facing the travails of brain injury or dementia.

Another way to unleash buried brilliance would be to apply tDCS—or a related technology called repetitive transcranial magnetic stimulation—as a form of "thinking cap" that would toggle brain regions on and off to potentially augment a person's creative capacity. A technological solution may not be an absolute prerequisite, however. Meditation or simple adherence to assiduous practice of an artistic skill may suffice to allow us to switch on the more creative aspects of the brain and thus explore undiscovered artistic capabilities.

As investigators understand the brain better, they may find other ways of determining what happens when brain circuits are turned up or down. Diffusion tensor imaging (DTI) and diffusion tensor tracking (DTT), which pinpoint connections among neurons ("fiber tracking"), are better suited than earlier methods for revealing the intricacies of the wiring inside a person's head, enabling researchers to correlate brain activity to the sudden appearance of skills. These more precise technologies can provide three-dimensional images of the fibers that tie together brain cells.

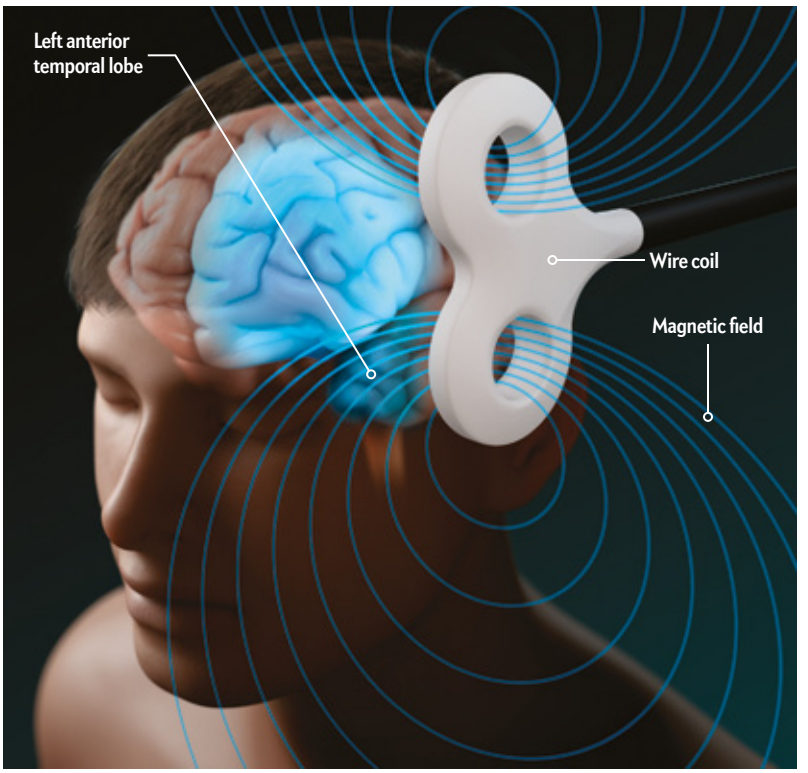
One challenge to uncovering the neurobiology underlying savantism has been the difficulty of observing brains as they carry out creative tasks that require movement. Not only is it hard to sculpt or play a piano inside an MRI machine, but any movement compromises image acuity. A newer technique—near-infrared spectroscopy (NIRS)—would sidestep such problems by replacing bulky machines with a comfortable skullcap that measures the amount of oxygen in blood flowing through the brain's blood vessels and relays the information to image-processing software. Even more promising is a recently developed helmet that uses another imaging method—positron-emission tomography (PET)—for monitoring when a person is sitting, standing or even exercising.

Such studies are worth pursuing. Acquired savantism provides strong evidence that a deep well of brain potential resides within us all. The challenge now is to find the best ways to tap into our inner savant—that little bit of Rain Man—while keeping the rest of our mental faculties intact. **M**

NEURAL ENHANCEMENT

Instant Savant

A technology called repetitive transcranial magnetic stimulation can temporarily unleash savantlike abilities and offers a way to investigate how those abilities arise. When a coil placed over the left temple delivers a pulsed magnetic field through the skull, the field apparently turns off brain circuits in the left temporal area that process words and other information. Right-brain circuits dedicated to spatial tasks take on a more expansive role in mental processing. In some cases, subjects exposed to the magnetic fields were better able to guess the quantity of a large collection of objects.



AXS BIOMEDICAL ANIMATION STUDIO

MORE TO EXPLORE

- **Savant-Like Skills Exposed in Normal People by Suppressing the Left Fronto-Temporal Lobe.** Allan W. Snyder et al. in *Journal of Integrated Neuroscience,* Vol. 2, No. 2, pages 149–158; December 2003.
- **Islands of Genius: The Bountiful Mind of the Autistic, Acquired, and Sudden Savant.** Darold A. Treffert. Jessica Kingsley Publishers, 2010.
- **Struck by Genius: How a Brain Injury Made Me a Mathematical Marvel.** Jason Padgett and Maureen Seaberg. Houghton Mifflin Harcourt, 2014.

From Our Archives

- **Islands of Genius.** Darold A. Treffert and Gregory L. Wallace in *Scientific American*; June 2002.

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NURTURING THE YOUNG GENIUS

RENEWING OUR COMMITMENT TO GIFTED EDUCATION IS THE KEY TO A MORE INNOVATIVE, PRODUCTIVE AND CULTURALLY RICH SOCIETY

BY RENA F. SUBOTNIK, PAULA OLSZEWSKI-KUBILIUS AND FRANK C. WORRELL

In 1957, when Sputnik took the world by storm, the Ford Foundation was several years into a project for talented students based on early college entrance. An evaluation of that program from the Fund for the Advancement of Education read: "There are those who argue that it is psychologically unsound and politically undemocratic for one child to proceed faster or to have a richer academic diet than another.... But what is too often ignored is the greatest risk of all—the risk of adhering stubbornly to a clearly imperfect set of practices which are frustrating the development of young talent at a time in history when this nation urgently needs to develop its human resources to the full."

The authors argued that, in a democracy, focusing on the *most* able students is critical for nurturing a cadre of capable leaders, among other advantages. The resulting infusion of attention and resources to talented

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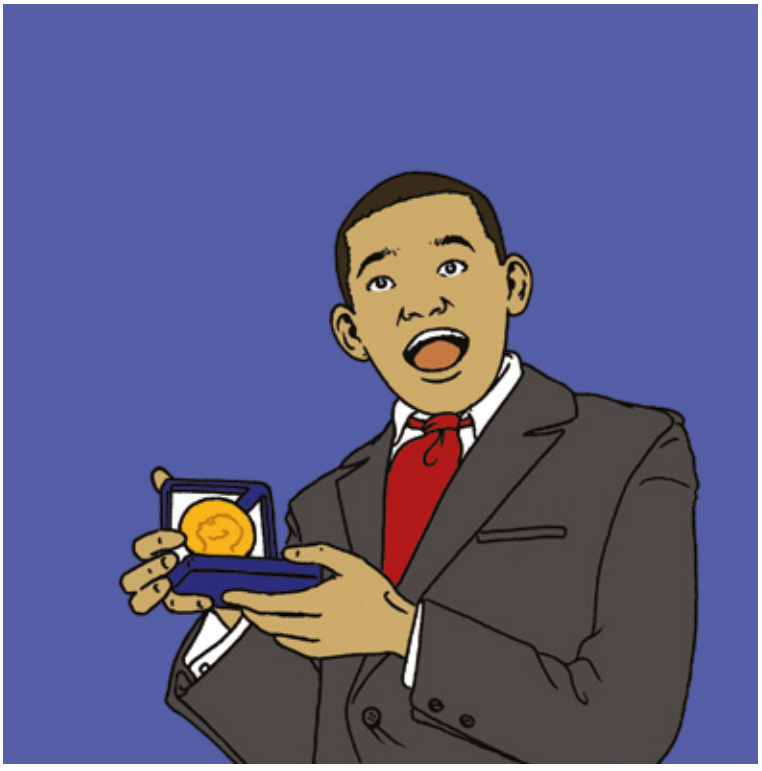

PROVIDING MORE OPPORTUNITIES FOR GIFTED CHILDREN WILL BOOST OUR SUPPLY OF FUTURE LEADERS, CREATIVE THINKERS AND INSPIRING PERFORMERS AND WILL THUS GREATLY IMPROVE OUR LIVES.

youth through the National Defense Education Act led to a boom of innovation and scientific productivity in the U.S.

Today researchers, policy makers and teachers pay little to no attention to high-achieving students. School-based gifted education receives scant state or federal funding. Only four states currently fund their mandates to identify and serve gifted students. Many such students spend their days in school unchallenged—relearning material they have already mastered. The failure to develop talented students means that fewer of them will become future innovators of products and services; creative thinkers to solve major social, economic and environmental problems; leaders to tackle national priorities; or performers to entertain, inspire and soothe our souls.

America's neglect of its talent is showing, particularly where math is concerned. Twenty-five of the 61 countries that participated in the 2012 Program for International Student Assessment (PISA) study, which tests the reading, science, and math skills and knowledge of 15-year-old children, had larger percentages of high-achieving math students than the U.S. did. Japan, Switzerland, Belgium and the Netherlands have nurtured at least twice the proportion of mathematically advanced students that the U.S. has and Singapore and South Korea three times more.

We think a renewed commitment to gifted education is critical for expanding the pool of individuals who can make pathbreaking discoveries and creative contributions to our society. The first step is to train teachers and others to spot giftedness, which may show up in a child's IQ score but could also surface as aptitudes in specific areas such as number sense or musical ability. Social and emotional qualities that can be developed through training, such as persistence, grit and passion, are also important contributors to later success.

Offering young children a wide palette of activities could spawn new interests and enable a greater diversity of talents to surface. Once an exceptional aptitude emerges, we need programs to be in place, including accelerated classes and psychological coaching, that can nurture its development as early and vigorously as possible. The chief goal of these efforts is preparing young people for outstanding achievement.

Talent

For nearly a century scholars have sought to understand, measure and explain giftedness. To some, the term is a misnomer for the result of endless practice or social advantage. We believe, however, that extraordinary abilities do exist and do matter. Giftedness implies an ability to perform at the extreme upper end of the distribution in a certain area. Early on it is determined and largely defined by potential, followed by demonstrated achievement and, later, by eminence. In elementary schools, it is often equated with IQ. Students who score above the 95th percentile (although cutoffs vary) on an intelligence test are often classified as gifted.

IQ is generally predictive of achievement in school, but new research shows that narrower, subject-specific academic assessments can help forecast the likelihood of adult contributions to, say, literature or physics. In 2005 psychologist David Lubin-

FAST FACTS

FAST-TRACKING TALENT

1. Abilities matter, particularly abilities in specific domains. They are malleable, however, and need to be cultivated.
2. Society needs to provide opportunities for intellectual enrichment to all students to ferret out hidden talents.
3. Psychological strengths such as persistence, social skills and strategic risk taking are determining factors in the successful development of talent. Being psychologically strong ensures that more children and youth have the wherewithal to take challenges and opportunities that are offered.

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ski of Vanderbilt University and his colleagues reported that scores on the math and verbal parts of the SAT measured around age 13 in high-achieving students (as well as tests of student interests) can indicate whether an adolescent will choose to later pursue the humanities or a math or science field as a career. Even differences within the 99th percentile of scores for mathematical ability—the top 1 percent—are associated with variations in outcomes, such as a student's eventual income level, number of patents and the likelihood of obtaining a doctorate.

EVEN DIFFERENCES WITHIN THE TOP 1 PERCENT OF MATHEMATICAL ABILITY ARE ASSOCIATED WITH VARIATIONS IN INCOME LEVEL, NUMBER OF PATENTS AND LIKELIHOOD OF OBTAINING A DOCTORATE.

In recent years educators have begun to look beyond IQ scores to measure giftedness. Specialized schools or programs for science or the arts admit students based on achievement-test scores, essays and projects. Elementary school programs may ask teachers to complete checklists that reveal a student's commitment to learning. As we discover how to better identify the core abilities associated with each domain of knowledge and skill, methods will evolve that are more valid and reliable.

The nonacademic domains are more advanced on this front. For example, New York–based choreographer and ballet dancer Eliot Feld, who has had years of experience building dance troupes and educating novice performers, identifies potential dancers around the age of eight using indicators of flexibility, body proportion and physical memory. Characteristics such as pitch perception and audiation—a way of cognitively processing music—have been associated with musical performance. In response to a survey, voice teachers identified intonation, timbre, musicality and pitch control as important factors related to singing talent.

Our ability to identify and assess the aptitudes that matter varies, however. In athletics, dance, music and chess, experts have developed visible benchmarks of talent at various ages. In academics, so far only in mathematics have we begun to generate reliable ways to detect potential talent early on.

Commitment

To achieve greatness in any realm requires more than talent. It also demands extraordinary creativity, grit, passion and social skills. Creativity, the ability to come up with novel, useful and elegant ideas or ways of doing things, has a long historical association with giftedness. It may depend on relevant skills and knowledge, but at its essence are mental processes such as metaphorical thinking, tolerance for complexity and flexibility in problem solving.

Precursors of adult creativity may include independent thinking, a willingness to entertain different perspectives and views, and the creation of projects and products that are novel when compared with those of one's peers. Children who exhibit these characteristics are more likely to make creative contributions as adults. In 1999 educational psychologist Jonathan Plucker, now at the University of Connecticut, reported results from a multidecade follow-up of students identified as creative with the Torrance Tests of Creative Thinking while they were in elementary school. Scores on this test, which largely measures divergent thinking, were three times better than IQ tests at predicting the quantity and quality of publicly recognized creative accomplishments in adulthood.

Aside from their ability and creativity, gifted individuals stand out in the commitment and sacrifice they are willing to make in pursuit of their goals. In a chapter in a 1985 book entitled *Advances in Motivation and Achievement,* psychologist Mihaly Csikszentmihalyi wrote, "The unifying similarity among geniuses and innovators is not cognitive or affective but motivational. What is common among them is the unwillingness or inability to strive for goals everyone else accepts."

Giftedness has long been associated with high levels of intrinsic motivation—that is, engaging in a

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task for the sake of learning. In fact, many high academic achievers are also motivated by and enjoy extrinsic factors such as trophies, scholarships and other forms of recognition. In a 2010 study school psychologist David J. Kover, then at the San Francisco Unified School District, and one of us (Worrell) showed that a group of academically talented students had similar levels of intrinsic and extrinsic motivation. High achievers may hunger more than others not only for knowledge but also for fame, fortune or power to change the world.

THOSE YOUTHS WHO HAD BEEN INVOLVED IN MORE EDUCATIONAL ACTIVITIES AND CLASSES HAD, AT AGE 33, A HIGHER RATE OF NOTABLE ACCOMPLISHMENTS IN SCIENCE, TECHNOLOGY OR MATH.

In 1978 Joseph Renzulli introduced the idea that one of the most distinguishing features of high achievers is their task persistence and motivation. In other words, they are willing to engage in study and practice that, though not necessarily enjoyable, is instrumental to improvement. In a 2008 study psychologist Timothy W. Curby, now at George Mason University, and his colleagues demonstrated that the kindergarten pupils most likely to be identified as gifted in third grade exhibited not only high cognitive ability but also early task orientation, which is "the ability to do and complete work even in an environment in which teachers may not be directly supervising the work or when there are distractions present." In findings published in 1990 psychologists Camilla P. Benbow and Olya Arjmand, then at Iowa State University, used a statistical method to determine variables that distinguished between high and low achievers in mathematics among 356 students identified as mathematically gifted based on their SAT scores. Their analysis revealed that the strongest long-term predictor of high achievement in a related area—going to medical school or graduate school for math or science—was the number of optional math and science examinations the students had taken, a variable that reflects a *commitment* to the discipline.

Passion contributes to the development of great ideas and performances, although it has been rarely studied in the context of gifted education. In one exception, psychologist Jennifer A. Fredricks of Connecticut College and her colleagues examined the quality in a 2010 study of 66 high school and college students who had been identified as gifted in academics, sports or the arts in childhood. The athletes and artists readily expressed passion about their involvement, telling experimenters, for instance, "I love the game … I want to play all the time." Among academically gifted youths, however, a typical statement was: "Well, I don't get all excited or anything—I mean, it's schoolwork." The study suggested that the way academics are currently taught does not instill passion, but with a greater focus on problem solving, creative thinking and learning authentic methods of a discipline, we might better foster that passion among academically gifted students. Further, the students might have displayed interest in specific subjects if the survey had been structured that way.

Opportunity

Although the goal of education in the U.S. is for all children to maximize their potential, the focus of funding has primarily been on the most vulnerable children, such as those with disabilities, who are rightly guaranteed a free appropriate public education. Educators and policy makers assume that academically gifted children will be successful no matter what their educational environment. Yet research has shown that it takes about 10,000 hours of guided study or practice to reach levels of expertise in most domains. Although substantial numbers of children with outstanding intellectual ability are singled out and receive at least some support, few of these youngsters become eminent in adulthood, suggesting that many are not receiving the guidance and instruction they need to fulfill their potential.

A key to developing this talent may lie in giving students lots of opportunities to pursue their interests. In a 2010 study Jonathan Wai of Duke University and his colleagues assessed participation in various educational opportunities such as academic competitions, research apprenticeships, academic clubs, summer programs and accelerated

See the *Psychological Science in the Public Interest* article "Rethinking Giftedness and Gifted Education: A Proposed Direction Forward Based on Psychological Science," on which this story for *Scientific American Mind* was originally based, at the Association for Psychological Science's Web site: **www.psychologicalscience.org**

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ABILITY MATTERS FOR ACHIEVEMENT, BUT EXPERTISE IN ANY DOMAIN REQUIRES A LOT (ABOUT 10,000 HOURS) OF HARD WORK. RECENT DATA SUGGEST THAT MANY GIFTED CHILDREN ARE NOT RECEIVING THE GUIDANCE AND INSTRUCTION THEY NEED TO FULFILL THEIR POTENTIAL.

classes among 1,467 individuals who had been identified as talented in math at age 13. They found that those who had been involved in more of these activities and classes—what the authors called a larger "educational dose"—had, at age 33, a higher rate of notable accomplishments in science, technology or math, such as earning a Ph.D., obtaining patents or securing tenure.

Effective talent development requires different kinds of teachers at different stages. Mentorship is vital for transforming ability into renown. In a study of the origins of eminence through mentorship published in 1977, sociologist Harriet Zuckerman of Columbia University interviewed 92 Americans who had won a Nobel Prize in science between 1901 and 1972. She found that more than half the interviewees had studied or collaborated with previous laureates. These mentors helped their protégés develop a feel for important problems and elegant solutions and mobilized resources, such as access to grants, fellowships, jobs and publications, on their behalf.

Developing youthful talents, especially in low-income and rural communities, by extending and supplementing the regular curriculum can expose children to new topics and ideas and enable them to engage with a subject in more depth. Summer programs, for example, may feature a range of topics that are not typically available in the regular classroom, such as human anatomy for fourth graders and robotics for middle schoolers.

Such enrichment activities are a staple of most gifted programs in schools, but expanding them could ferret out new talent. Courses that introduce subjects typically not studied until high school or college, for example, may give interested and able students a head start. In some cases, students may take these courses in specialized schools for gifted students such as the Illinois Mathematics and Science Academy and New York City's Brooklyn Technical High School and Bronx High School of Science.

The greater the diversity of offerings, the greater are our chances of unmasking potential. In 2004 the news program *60 Minutes* ran a piece on low-income adolescents of color from Harlem, four of whom were representing the U.S. at the Olympics in fencing that year. How did students from low-income backgrounds living in an inner-city neighborhood get involved in such an esoteric sport? By good fortune, a former African-American fencing champion had retired to Harlem and began giving lessons 15 years earlier. His work provided the opportunity for many youngsters who may never have held a sword to discover that they had a talent for the sport

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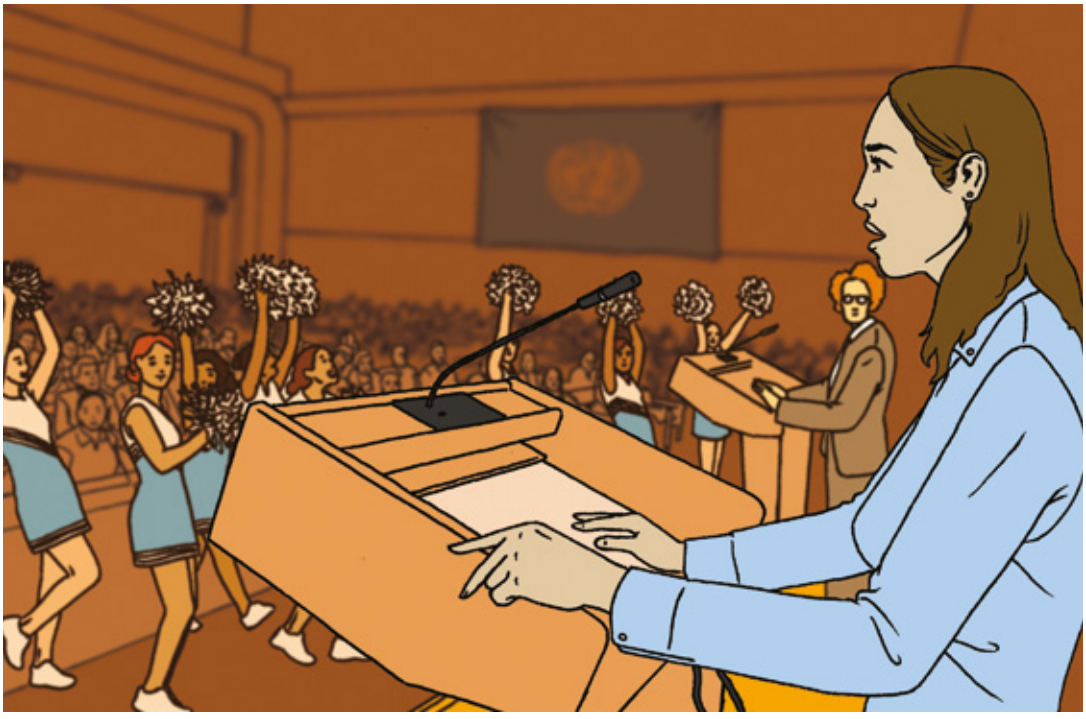

GIFTED KIDS MAY BE INTRINSICALLY DRIVEN, BUT THEY WANT PUBLIC RECOGNITION, TOO. SCHOOLS TEND TO CELEBRATE ACADEMIC ACCOMPLISHMENTS FAR LESS THAN THOSE IN, SAY, ATHLETICS. FINDING WAYS TO CHEER ON OR CELEBRATE INTELLECTUAL FEATS COULD ENCOURAGE HIGH ACADEMIC ACHIEVEMENT.

(as well as the interest, passion and commitment to pursue it).

Students who seize such opportunities and demonstrate sufficient commitment should be given access to increasingly challenging classes or competitions, regardless of their age. Academic acceleration may involve skipping a grade, entering a higher grade level in a single subject or enrolling early in Advanced Placement courses. It may also consist of speeding up instruction in a course so that two years of material are covered in one year.

Acceleration significantly boosts both achievement and motivation in gifted students. In several meta-analyses reported in 2004 by psychologist James A. Kulik, now at the University of California, San Diego, he found that accelerated elementary and secondary students demonstrated levels of achievement superior to mainstreamed gifted students of the same age and ability. Kulik also found that accelerated students were more likely to seek degrees beyond a bachelor's. In the same year gifted education specialist Karen B. Rogers of the University of St. Thomas in Saint Paul, Minn., reported that accelerated students placed in various types of programs advanced beyond their peers between two and seven months, with greater improvement seen in classrooms in which students covered several years of content in an academic year.

Schools hardly ever use acceleration strategies. Educators often cite scheduling difficulties, but in fact, a strong bias exists against them. Yet acceleration should be a key part of gifted education. Indeed, we should expect children with talent to increasingly channel their efforts into specific areas as they mature. They may be able to do so by buying time for enrichment, apprenticeships and other exploratory programs through showing early mastery of content. Schools should be staffed with extremely knowledgeable teachers even at the earliest grades, and we need more affordable summer programs that compress semester-long or yearlong courses into a few weeks of intensive instruction.

Persistence

Providing opportunities is not enough, however. Talented individuals must take advantage of them. Research shows that young people may shy away from educational or extracurricular offerings for various reasons, including fear of competition and failure, poor study and organizational skills, and shyness. Capitalizing on favorable circumstances thus requires certain psychological strengths,

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among them an ability to cope with challenges and criticism and a willingness to take strategic risks.

Such traits, along with persistence, focus and drive, also support the ability to undergo the intense practice and preparation necessary to reach the top. In a 2001 study sports psychologist Daniel Gould of Michigan State University and his colleagues investigated the development of psychological strength in U.S. Olympic champions. Becoming a champion requires more than just athletic prowess. It also depends on an ability to focus, mental toughness, facility with setting goals, competitiveness, confidence, coachability, drive, optimism and emotional control.

BECOMING AN OLYMPIC CHAMPION REQUIRES MORE THAN JUST ATHLETIC PROWESS; IT ALSO DEPENDS ON AN ABILITY TO FOCUS, MENTAL TOUGHNESS, DRIVE, OPTIMISM AND EMOTIONAL CONTROL.

Coaches routinely teach elite athletes how to handle setbacks, adjust anxiety levels for optimal performance and imagine success. In recent years music conservatories have given more systematic attention to these skills. The Juilliard School's precollege and conservatory programs implicitly inculcate values, such as deep devotion to one's art and teachers, that are associated with successful negotiation of the conservatory years. The school has also offered courses on mental-skills training to directly address variations in outcome, from music star to underachiever.

Academically talented students can experience competitive and occasionally stressful environments. Although these individuals often display extraordinary motivation and commitment, they rarely receive additional psychological coaching to deal with the rigors of acceleration, peer comparisons, and other challenges. School and college teachers receive no systematic training in this realm. Neither are they typically trained to boost creativity through exercises that invigorate metaphorical and divergent thinking or problem solving.

Schools could do more to encourage high academic achievement, too. Although teachers and administrators often publicly recognize accomplishments in athletics, leadership and the performing arts, they tend to ignore or downplay academic feats. Stereotyping kids with intellectual talents as "nerds" or "brainiacs" betrays a lack of support for these children, many of whom work very hard to meet their goals. It may also send a message to other students that high achievement is not worthy of teacher attention or recognition.

Indeed, the idea that gifted children are "naturals" and do not need to study or practice can severely undercut motivation. According to research by psychologist Carol S. Dweck of Stanford University, the assumption that intelligence and talent are fixed traits can lead people to focus primarily on proving themselves worthy of their gifted or "smart" label and to undervalue the role of effort in achievement. In contrast, believing that intelligence and talent are malleable motivates a person to put in the daunting amount of effort necessary to achieve goals such as becoming a respected physicist, historian or philosopher. Dweck's research suggests that this attitude can be fostered with proper instruction and parenting practices [see "The Secret to Raising Smart Kids," by Carol S. Dweck, on page 76].

The aim of our proposed framework is to increase the number of individuals who can develop the innovative products and services and deliver the creative performances that can improve and enhance our lives. The world needs more of these people. We are not advocating that all services be channeled to those on the path to eminence. Yet a focus on eminence sustains a continued attention to excellence. When people are given the means to transform talent into transcendent achievement, they experience great personal satisfaction and, at the same time, deliver unimaginable benefits to society. M

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HOW TO BUILD A BETTER LEARNER

BRAIN STUDIES SUGGEST NEW WAYS TO IMPROVE READING, WRITING AND ARITHMETIC—AND EVEN SOCIAL SKILLS

By Gary Stix

PHOTOGRAPH BY ANDREW HETHERINGTON

Thinking cap records electrical signals from the brain of one-year-old Elise Hardwick, who is helping scientists figure out how the youngest children process sounds that make up the building blocks of language.

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Eight-month-old Lucas Kronmiller has just had the surface of his largely hairless head fitted with a cap of 128 electrodes. A research assistant in front of him is frantically blowing bubbles to entertain him. But Lucas seems calm and content. He has, after all, come here, to the Infancy Studies Laboratory at Rutgers University, repeatedly since he was just four months old, so today is nothing unusual. He—like more than 1,000 other youngsters over the past 15 years—is helping April A. Benasich and her colleagues to find out whether, even at the earliest age, it is possible to ascertain if a child will go on to experience difficulties in language that will prove a burdensome handicap when first entering elementary school.

Benasich is one of a cadre of researchers who have been employing brain-recording techniques to understand the essential processes that underlie learning. The new science of neuroeducation seeks the answers to questions that have always perplexed cognitive psychologists and pedagogues.

How, for instance, does a newborn's ability to process sounds and images relate to the child's capacity to learn letters and words a few years later? What does a youngster's ability for staying mentally focused in preschool mean for later academic success? What can educators do to foster children's social skills—also vital in the classroom? Such studies can complement the wealth of knowledge established by psychological and educational research programs.

They also promise to offer new ideas, grounded in brain science, for making better learners and for preparing babies and toddlers for reading, writing, arithmetic, and survival in the complex social network of nursery school and beyond. Much of this work focuses on the first years of life and the early grades of elementary school because some studies show that the brain is most able to change at that time.

The Aha! Instant

Benasich studies anomalies in the way the brains of the youngest children perceive sound, a cognitive process fundamental to language understanding, which, in turn, forms the basis for reading and writing skills. The former nurse, who later earned two doctorates, focuses on what she calls the aha! instant—an abrupt transition in electrical activity in the brain that signals that something new has been recognized [see "The Aha! Moment," by Nessa Bryce, on page 48].

Researchers at Benasich's lab in Newark, N.J., expose Lucas and other infants to tones of a certain frequency and duration. They then record a change in the electrical signals generated in the brain when a different frequency is played. Typically the electroencephalogram (EEG) produces a strong oscillation in response to the change—indicating that the brain essentially says, "Yes, something has changed"; a delay in the response time to the different tones means that the brain has not detected the new sound quickly enough.

The research has found that this pattern of sluggish electrical activity at six months can predict language issues at three to five years of age. Differences in activity that persist during the toddler and preschool years can foretell problems in development of the brain circuitry that processes the rapid transitions occurring during perception of the basic units of speech. If children fail to hear or process components of speech—say, a "da" or a "pa"—quickly enough as toddlers, they may lag in "sounding out" written letters or syllables in their head, which could later impede fluency in reading. These findings offer more rigorous confirmation of other research by Benasich showing that children who encounter early problems in processing these sounds test poorly on psychological tests of language eight or nine years later.

If Benasich and others can diagnose future language problems in infants, they may be able to correct them by exploiting the inherent plasticity of the developing brain—its capacity to change in response to new experiences. They may even be able to improve basic functioning for an infant whose brain is developing normally. "The easiest time to make sure that the brain is getting set up in a way that's optimal for learning may be in the first part of the first year," she says.

Games, even in the crib, could be one answer. Benasich and her team have devised a game toy that trains a baby to react to a change in tone by turning the head or shifting the eyes (detected with a tracking sensor). When the movement occurs, a video snippet plays, a reward for good effort.

In a study reported in 2014 babies who went through this training detected tiny modulations within the sounds faster and more accurately than did children who only listened passively or had no exposure to the sounds at all. Based on this research, Benasich believes that the game would assist infants impaired in processing these sounds to respond more quickly. She is now working on an interactive game that could train infants to perceive rapid sound sequences.

The Number Sense

Flexing cognitive muscles early on may also help infants tune rudimentary math skills. Stanislas Dehaene, a neuroscientist at the French National Institute of Health and Medical Research, is a leader in the field of numerical cognition who has tried to develop ways to help

FAST FACTS

EARLY EXERCISES

1. The technology and research methods of the neuroscientist have started to reveal, at the most basic level, what happens in the brain when we learn something new.
2. As these studies mature, it may become possible for a preschooler or even an infant to engage in simple exercises to ensure that the child is cognitively equipped for school.
3. If successful, such interventions could potentially have a huge effect on educational practices by dramatically reducing the incidence of various learning disabilities. But scientists, educators and parents must beware overstated claims for brain-training methods that purport to help youngsters but have not been proved to work.

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children with early math difficulties. Babies have some capability of recognizing numbers from birth. When the skill is not in place from the beginning, Dehaene says, a child may later have difficulty with arithmetic and higher math. Interventions that build this "number sense," as Dehaene calls it, may help the slow learner avoid years of difficulty in math class.

This line of research contradicts that of famed psychologist Jean Piaget, who contended that the brains of infants are blank slates, or tabula rasa, when it comes to making calculations in the crib. Children, in Piaget's view, have to develop a basic idea of what a number is from years of interacting with blocks, Cheerios or other objects. They eventually learn that when the little oat rings get pushed around a table, the location differs, but the number stays the same.

The neuroscience community has amassed a body of research showing that humans and other animals have a basic numerical sense. Babies, of course, do not spring from the womb performing differential equations in their head. But experiments have found that toddlers will routinely reach for the row of M&Ms that has the most candies. And other research has demonstrated that even infants only a few months old comprehend relative size. If they see five objects being hidden behind a screen and then another five added to the first set, they convey surprise if they see only five when the screen is removed.

Babies also seem to be born with other innate mathematical abilities. Besides being champion estimators, they can also distinguish exact numbers—but only up to the number three or four. Dehaene was instrumental in pinpointing a brain region—a part of the parietal lobe (the intraparietal sulcus)—where numbers and approximate quantities are represented. (Put a hand on the rear portion of the top of your head to locate the parietal lobe.)

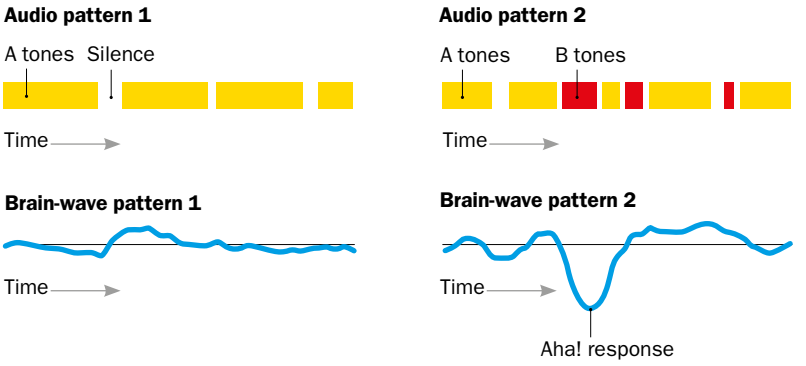
The ability to estimate group size, which also exists in dolphins, rats, pigeons, lions and monkeys, is probably an evolutionary hand-me-down that is required to gauge whether your clan should fight or flee in the face of an enemy and

Toning Up for Language: Early Education in the Crib

Scientists at Rutgers University have developed tests to determine whether babies with normal hearing process sound optimally deep within the brain (*top panel*). They are exploring whether a game they are devising (*bottom panel*) might ready the youngest children for speaking, listening, reading and writing.

Waiting for "Aha!"

The Infancy Studies Laboratory at Rutgers uses an electrode cap to record brain activity while babies listen to different sounds. First, they hear high-frequency tones (*labeled A*), which elicit a certain brain-wave pattern (*left*). Tones of different pitch (*labeled B*) intersperse with the initial tones and cause a temporary shift in the brain wave (the aha! response) as the brain detects the change (*right*). A slower or weaker response to this sudden change in pitch may predict language problems in later life.



A Game for Babies

Infants at Rutgers can learn to process sound more efficiently while also having fun. A child learns to turn the head in response to the B tones (*left*) but not to the A tones (*right*) and is rewarded with a snippet of a video for a correct response. The pace of tone sequences speeds up, and the child learns to respond more and more accurately to this fast tempo.

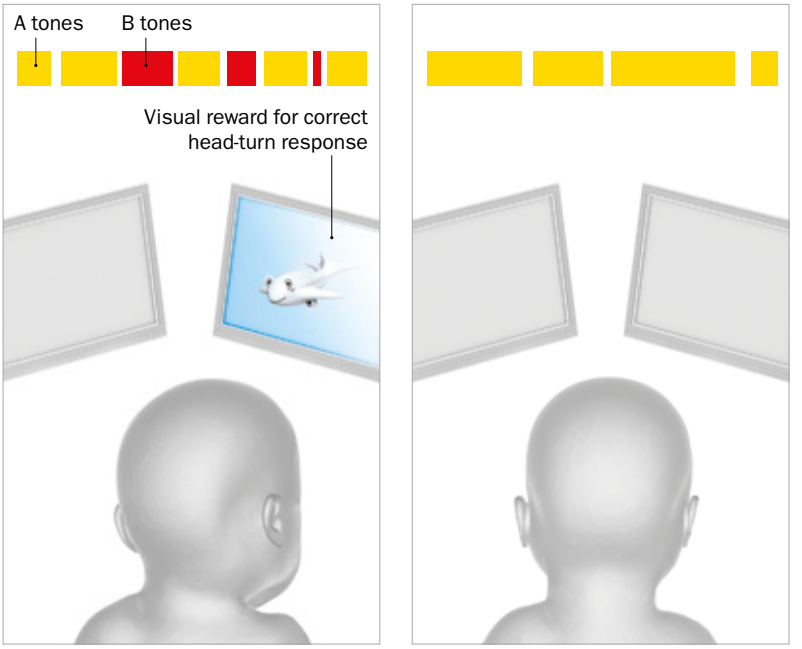


ILLUSTRATION BY BRYAN CHRISTIE, GRAPHICS BY JEN CHRISTIANSEN; SOURCES: CYNTHIA ROESLER, APRIL A. BENASICH, TERESA REALPE AND NASEEM CHOUDHURY *Rutgers University*

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to ascertain which tree bears the most fruit for picking. Dehaene, along with linguist Pierre Pica of the National Center for Scientific Research in France and colleagues, discovered more evidence for this instinctive ability through work with the Mundurukú Indians in the Brazilian Amazon, a tribe that has only an elementary lexicon for numbers. Its adult members can tell whether one array of dots is bigger than another, performing the task almost as well as a French control group did, yet most are unable to answer how many objects remain when four objects are removed from a group of six.

This approximation system is a cornerstone on which more sophisticated mathematics is constructed. Any deficit in these innate capacities can spell trouble later. In the early 1990s Dehaene hypothesized that children build on their internal ballpark estimation system for more sophisticated computations as they get older. Indeed, in the years since then, a number of studies have found that impaired functioning of the primitive numerical estimation system in youngsters can predict that a child will perform poorly in arithmetic and standard math achievement tests from the elementary years onward. "We realize now that the learning of a domain such as arithmetic has to be founded on certain core knowledge that is available already in infancy," Dehaene says.

It turns out that dyscalculia (the computational equivalent of dyslexia), which is marked by a lag in computational skills, affects 3 to 7 percent of children. Dyscalculia has received much less attention from educators than dyslexia has for reading—yet it may be just as crippling. "They earn less, spend less, are more likely to be sick, are more likely to be in trouble with the law, and need more help in school," notes a review article that appeared in *Science* in May 2011.

As with language, early intervention may help. Dehaene and his team devised a simple computer game they hope will enhance mathematical ability. Called the Number Race, it exercises these basic abilities in children aged four to eight. In one version, players must choose the larger of two quantities of gold pieces before a computer-controlled opponent steals the biggest pile. The game adapts automatically to the skill of the player, and at the higher levels the child must add or subtract gold before making a comparison to determine the biggest pile. If the child wins, she advances forward a number of steps equal to the gold just won. The first player to get to the last step on the virtual playing board wins.

The open-source software, which has been translated into eight languages, makes no hyperbolic claims about the benefits of brain training. Even so, more than 20,000 teachers have downloaded the software from a government-supported research institute in Finland. To-

Count on It: Born to Estimate

From the time we are born, we have some concept of number. Children with deficits in this innate skill often end up struggling in later life. Stanislas Dehaene and his colleagues have created a game, the Number Race, intended to bolster our natural-born ability to estimate quantity. A preschooler judges which group of gold pieces is larger before the computer's animal avatar can steal the bigger pile (*top left*). A correct guess by the child advances his or her avatar a comparable number of spaces from its previous position; the loser moves ahead by a number equal to the smaller quantity of coins (*bottom right*). The winner is the one to reach the end of the number line first.

ILLUSTRATION BY QUICKHONEY; MODIFIED FROM "PRINCIPLES UNDERLYING THE DESIGN OF 'THE NUMBER RACE.' AN ADAPTIVE COMPUTER GAME FOR REMEDIATION OF DYSCALCULIA," BY ANNA J. WILSON, STANISLAS DEHAENE, PHILIPPE PINEL, SUSANNAH K. REVKIN, LAURENT COHEN AND DAVID COHEN, IN *BEHAVIORAL AND BRAIN FUNCTIONS*, VOL. 2; 2006

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day it is being tested in several controlled studies to see whether it prevents dyscalculia and whether it helps healthy children bolster their basic number sense.

Get Ahold of Yourself

The cognitive foundations of good learning depend heavily on what psychologists call executive function, a term encompassing such cognitive attributes as the ability to be attentive, hold what you have just seen or heard in the mental scratch pad of working memory, and delay gratification. These capabilities may predict success in school and even in the working world. In 1972 a famous experiment at Stanford University—"Here's a marshmallow, and I'll give you another if you don't eat this one until I return"—showed the importance of executive function. Children who could wait, no matter how much they wanted the treat, did better in school and later in life.

In the 21st century experts have warmed to the idea of executive function as a teachable skill. An educational curriculum called Tools of the Mind has had success in some low-income school districts, where children typically do not fare as well academically compared with high-income districts. The program trains children to resist temptations and distractions and to practice tasks designed to enhance working memory and flexible thinking.

In one example of a self-regulation task, a child might tell himself aloud what to do. These techniques are potentially so powerful that in centers of higher learning, economists now contemplate public policy measures to improve self-control as a way to "enhance the physical and financial health of the population and reduce the rate of crime," remark the authors of a study that appeared in 2011 in the *Proceedings of the National Academy of Sciences USA*.

Findings from neuroscience labs have bolstered that view and have revealed that the tedium of practice to resist metaphorical marshmallows may not be necessary. Music training can work as well. Echoing the *Battle Hymn of the Tiger Mother,* researchers are

Five Common Myths about the Brain

Some widely held ideas about the way children learn can lead educators and parents to adopt faulty teaching principles.

MYTH HUMANS USE ONLY 10 PERCENT OF THEIR BRAIN

FACT The 10 percent myth (sometimes elevated to 20) is mere urban legend, one perpetrated by the plot of the 2011 movie *Limitless,* which pivoted around a wonder drug that endowed the protagonist with prodigious memory and analytical powers. In the classroom, teachers may entreat students to try harder, but doing so will not light up "unused" neural circuits; academic achievement does not improve by simply turning up a neural volume switch.

MYTH "LEFT BRAIN" AND "RIGHT BRAIN" PEOPLE DIFFER

FACT The contention that we have a rational left brain and an intuitive, artistic right side is fable: humans use both hemispheres of the brain for all cognitive functions. The left brain/right brain notion originated from the realization that many (though not all) people process language more in the left hemisphere and spatial abilities and emotional expression more in the right. Psychologists have used the idea to explain distinctions between different personality types. In education, programs emerged that advocated less reliance on rational "left brain" activities. Brain-imaging studies show no evidence of the right hemisphere as a locus of creativity. And the brain recruits both left and right sides for both reading and math.

MYTH YOU MUST SPEAK ONE LANGUAGE BEFORE LEARNING ANOTHER

FACT Children who learn English at the same time as they learn French do not confuse one language with the other and so develop more slowly. This idea of interfering languages suggests that different areas of the brain compete for resources. In reality, young children who learn two languages, even at the same time, gain better generalized knowledge of language structure as a whole.

MYTH BRAINS OF MALES AND FEMALES DIFFER IN WAYS THAT DICTATE LEARNING ABILITIES

FACT Differences do exist in the brains of males and females, and the distinctive physiology may result in differences in the way their brains function. No research, though, has demonstrated gender-specific differences in how networks of neurons become connected when we learn new skills. Even if some gender differences do eventually emerge, they will likely be small and based on averages—in other words, they will not necessarily be relevant to any given individual.

MYTH EACH CHILD HAS A PARTICULAR LEARNING STYLE

FACT The notion that a pupil tends to learn better by favoring a particular form of sensory input—a "visual learner" as opposed to one who listens better—has not received much validation in actual studies. For this and other myths, public perceptions appear to have outstripped the science. Uta Frith, a neuroscientist who chaired a British panel that looked at the promise of neuroeducation, urges parents and educators to tread cautiously: "There is huge demand by the general public to have information about neuroscience for education. As a consequence, there's an enormous supply of totally untested, untried and not very scientific methods."

SOURCES: *MIND, BRAIN, AND EDUCATION SCIENCE,* BY TRACEY TOKUHAMA-ESPINOSA. W. W. NORTON, 2010; *UNDERSTANDING THE BRAIN: THE BIRTH OF A LEARNING SCIENCE.* OECD, 2007; OECD EDUCATIONAL MINISTERIAL MEETING, NOVEMBER 4–5, 2010

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finding that assiduous practice of musical instruments may yield a payoff in the classroom—invoking shades of "tiger mom" author Amy Chua, who insisted that her daughters spend endless hours on the violin and piano. Playing an instrument may improve attention, working memory and self-control.

Some of the research providing such findings comes from a group of neuroscientists led by Nina Kraus of Northwestern University. Kraus, head of the Auditory Neuroscience Laboratory there, grew up with a diverse soundscape at home. Her mother, a classical musician, spoke to the future neuroscientist in her native Italian, and Kraus still plays the piano, guitar and drums. "I love it—it's a big part of my life," she says, although she considers herself "just a hack musician."

Kraus has used EEG recordings to measure how the nervous system encodes pitch, timing and timbre of musical compositions—and whether neural changes that result from practicing music improve cognitive faculties. Her lab has found that music training enhances working memory and, perhaps most important, makes students better listeners, allowing them to extract speech from the all-talking-at-once atmosphere that sometimes prevails in the classroom.

Musical training as brain tonic is still in its infancy, and a number of questions remain unanswered about exactly what type of practice enhances executive function: Does it matter whether you play the piano or guitar or whether the music was written by Mozart or the Beatles? Critically, will music classes help students who have learning difficulties or who come from low-income school districts?

But Kraus points to anecdotal evidence suggesting that music training's impact extends even to academic classes. The Harmony Project provides music education to low-income youngsters in Los Angeles. Dozens of students participating in the project have graduated from high school and gone on to college, usually the first in their family to do so.

Kraus has worked with the Harmony Project and published a study in 2014 that showed that children in one of its programs who practiced a musical instrument for two years could process sounds closely linked to reading and language skills better than children who only did so for a year. Kraus is an advocate of the guitar over brain games. "If students have to choose how to spend their time between a computer game that supposedly boosts memory or a musical instrument, there's no question, in my mind, which one is more beneficial for the nervous system," Kraus says. "If you're trying to copy a guitar lead, you have to keep it in your head and try to reproduce it over and over."

Hype Alert

As research continues on the brain mechanisms underlying success in the "four Rs," three traditional ones with regulation of one's impulses as the fourth, many scientists involved with neuroeducation are taking pains to avoid overhyping the interventions they are testing. They are eager to translate their findings into practical assistance for children, but they are also well aware that the research still has a long way to go. They know, too, that teachers and parents are already bombarded by a confusing raft of untested products for enhancing learning and that some highly touted tools have proved disappointing.

In one case in point, a small industry developed several years ago around the idea that just listening to a Mozart sonata could make a baby smarter, a contention that failed to withstand additional scrutiny. Kraus's research suggests that to gain any benefit, you have to actually play an instrument, exercising auditory-processing areas of the brain: the more you practice, the more your abilities to distinguish subtleties in sound develop. Listening alone is not sufficient.

Similarly, even some of the brain-training techniques that claim to have solid scientific proof of their effectiveness have been questioned. A meta-analysis that appeared in the March 2011 issue of the *Journal of Child Psychology and Psychiatry* reviewed studies of perhaps the best known of all brain-training methods—software called Fast ForWord, developed by Paula A. Tallal of Rutgers, Michael Merzenich of the University of California, San Francisco, and their colleagues. The analysis found no evidence of effectiveness in helping children with language or reading difficulties. As with the methods used by Benasich, a former postdoctoral fellow with Tallal, the software attempts to improve deficits in the processing of sound that can lead to learning problems. The meta-analysis provoked a sharp rebuttal from Scientific Learning, the maker of the software, which claimed that the selection criteria were too restrictive, that most studies in the analysis were poorly implemented and that the software has been improved since the studies were conducted.

The clichéd refrain—more research is needed—applies broadly to many endeavors in neuroeducation. Dehaene's number game still needs fine adjustments before it receives wide acceptance. One controlled study showed that the game helped children compare numbers, although that achievement did not carry over into better counting or arithmetic skills. A new version is being released that the researchers hope will address these problems. Yet another finding has questioned whether music training improves executive function and thereby enhances intelligence.

In a nascent field, one study often contradicts another, only to be followed by a third that disputes the first two. This zigzag trajectory underlies all of science and at times leads to claims that overreach. In neuroeducation, teachers and parents have sometimes become the victims of advertising for "science-based" software and educational programs. "It's confusing. It's bewildering," says Deborah Rebhuhn, a math teacher at the Center School, a special-education institution in Highland Park,

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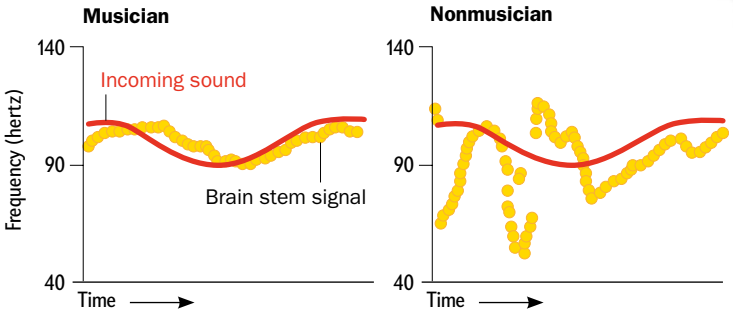
The Best Brain Training: Practice That Violin

Intensive musical training from a young age fosters skills beyond just an ability to play an instrument. The musician's concentration on the fine-grained acoustics of sound helps with language comprehension and promotes cognitive skills: attention, working memory and self-regulation.

BETTER LISTENERS

Musicians perceive sound more clearly than nonmusicians because practicing an instrument trains the entire brain. The sounds of an instrument travel from the cochlea in the inner ear to the primitive brain stem before moving to the cortex, a locus of high-level brain functions, and then back again to the brain stem and cochlea. This feedback loop allows the musician to recruit various brain areas to produce, say, the proper pitch for a tune. Monitoring of an electrical signal in the brain stem (*yellow graph line*) reveals the musician's exquisite sensitivity to pitch: the musician tracks an incoming sound wave (*red line*) more accurately than a nonmusician does.



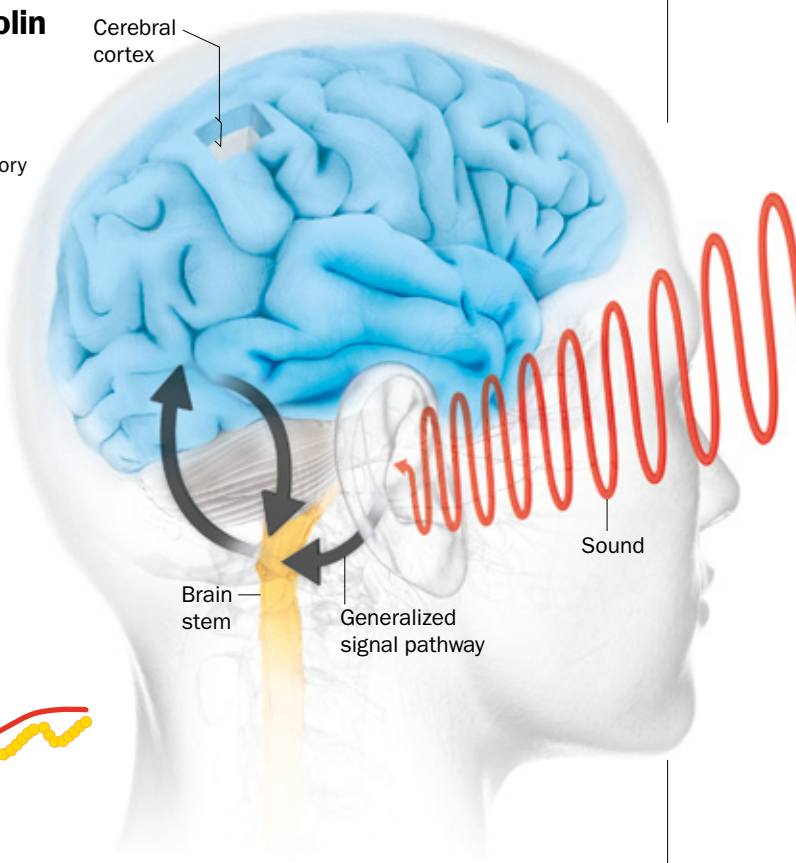


ILLUSTRATION BY BRYAN CHRISTIE, GRAPHICS BY JEN CHRISTIANSEN; SOURCE: "MUSICAL EXPERIENCE SHAPES HUMAN BRAINSTEM ENCODING OF LINGUISTIC PITCH PATTERNS," BY PATRICK C. M. WONG, ERIKA SKOE, NICOLE M. RUSSO, TASHA DEES AND NINA KRAUS, IN *NATURE NEUROSCIENCE*, VOL. 10, NO. 4; APRIL 2007 (*graphs*)

N.J., that accepts students from public schools statewide. "I don't know which thing to try. And there's not enough evidence to go to the head of the school and say that something works."

A Preschool Tune-up

Scientists who spend their days mulling over EEG wave forms and complex digital patterns in magnetic resonance imaging realize that they cannot yet offer definitive neuroscience-based prescriptions for improving learning. The work, however, is leading to a vision of what is possible, perhaps for Generation Z or its progeny. Consider the viewpoint of John D. E. Gabrieli, a professor of neuroscience participating in a collaborative program between Harvard University and the Massachusetts Institute of Technology. In a review article in *Science* in 2009, Gabrieli conjectured that eventually brain-based evaluation methods, combined with traditional testing, family history and perhaps genetic tests, could detect reading problems by age six and allow for intensive early intervention that might eliminate many dyslexia cases among school-aged children.

One study has already found that EEGs in kindergartners predict reading ability in fifth graders better than standard psychological measures. By undergoing brain monitoring combined with standard methods, each child might be evaluated before entering school and, if warranted, be given remedial training based on the findings that are trickling in today from neuroscience labs. If Gabrieli's vision comes to pass, brain science may imbue the notion of individualized education with a whole new meaning—one that involves enhancing the ability to learn even before a child steps foot in the classroom. M

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THE SECRET TO RAISING SMART KIDS

HINT:

DON'T TELL YOUR KIDS THAT THEY ARE. MORE THAN THREE DECADES OF RESEARCH SHOWS THAT A FOCUS ON "PROCESS"—NOT ON INTELLIGENCE OR ABILITY—IS KEY TO SUCCESS IN SCHOOL AND IN LIFE

BY CAROL S. DWECK

A brilliant student, Jonathan sailed through grade school. He completed his assignments easily and routinely earned As. Jonathan puzzled over why some of his classmates struggled, and his parents told him he had a special gift. In the seventh grade, however, Jonathan suddenly lost interest in school, refusing to do homework or study for tests. As a consequence, his grades plummeted. His parents tried to boost their son's confidence by assuring him that he was very smart. But their attempts failed to motivate Jonathan (who is a composite drawn from several children). Schoolwork, their son maintained, was boring and pointless.

Our society worships talent, and many people assume that possessing superior intelligence or

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Young people who believe that their intelligence alone will enable them to succeed in school are often discouraged when the going gets tough.

ability—along with confidence in that ability—is a recipe for success. In fact, however, more than 35 years of scientific investigation suggests that an overemphasis on intellect or talent leaves people vulnerable to failure, fearful of challenges and unwilling to remedy their shortcomings.

The result plays out in children like Jonathan, who coast through the early grades under the dangerous notion that no-effort academic achievement defines them as smart or gifted. Such children hold an implicit belief that intelligence is innate and fixed, making striving to learn seem far less important than being (or looking) smart. This belief also makes them see challenges, mistakes and even the need to exert effort as threats to their ego rather than as opportunities to improve. And it causes them to lose confidence and motivation when the work is no longer easy for them.

Praising children's innate abilities, as Jonathan's parents did, reinforces this mind-set, which can also prevent young athletes or people in the workforce and even marriages from living up to their potential. On the other hand, our studies show that teaching people to have a "growth mind-set," which encourages a focus on "process" (consisting of personal effort and effective strategies) rather than on intelligence or talent, helps make them into high achievers in school and in life.

FAST FACTS

GROWING PAINS

1. Many people assume that superior intelligence or ability is a key to success. But more than three decades of research shows that an overemphasis on intellect or talent—and the implication that such traits are innate and fixed—leaves people vulnerable to failure, fearful of challenges and unmotivated to learn.
2. Teaching people to have a "growth mind-set," which encourages a focus on "process" rather than on intelligence or talent, produces high achievers in school and in life.
3. Parents and teachers can engender a growth mind-set in children by praising them for their persistence or strategies (rather than for their intelligence), by telling success stories that emphasize hard work and love of learning, and by teaching them about the brain as a learning machine.

The Opportunity of Defeat

I first began to investigate the underpinnings of human motivation—and how people persevere after setbacks—as a psychology graduate student at Yale University in the 1960s. Animal experiments by psychologists Martin Seligman, Steven Maier and Richard Solomon, all then at the University of Pennsylvania, had shown that after repeated failures, most animals conclude that a situation is hopeless and beyond their control. After such an experience, the researchers found, an animal often remains passive even when it can effect change—a state they called learned helplessness.

People can learn to be helpless, too, but not everyone reacts to setbacks this way. I wondered: Why do some students give up when they encounter difficulty, whereas others who are no more skilled continue to strive and learn? One answer, I

PRECEDING PAGES: JIM CUMMINS *Getty Images*; THIS PAGE: GETTY IMAGES

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THE MOST PERSISTENT STUDENTS DO NOT RUMINATE ABOUT THEIR OWN FAILURE BUT THINK OF MISTAKES AS PROBLEMS TO BE SOLVED.

soon discovered, lay in people's beliefs about *why* they had failed.

In particular, attributing poor performance to a lack of ability depresses motivation more than does the belief that lack of effort is to blame. In 1972, when I taught a group of elementary and middle school children who displayed helpless behavior in school that a lack of effort (rather than lack of ability) led to their mistakes on math problems, the kids learned to keep trying when the problems got tough. They also solved many more problems even in the face of difficulty. Another group of helpless children who were simply rewarded for their success on easier problems did not improve their ability to solve hard math problems. These experiments were an early indication that a focus on effort can help resolve helplessness and engender success.

Subsequent studies revealed that the most persistent students do not ruminate about their own failure much at all but instead think of mistakes as problems to be solved. At the University of Illinois in the 1970s I, along with my then graduate student Carol Diener, asked 60 fifth graders to think out loud while they solved very difficult pattern-recognition problems. Some students reacted defensively to mistakes, denigrating their skills with comments such as "I never did have a good rememory," and their problem-solving strategies deteriorated.

Others, meanwhile, focused on fixing errors and honing their skills. One advised himself: "I should slow down and try to figure this out." Two schoolchildren were particularly inspiring. One, in the wake of difficulty, pulled up his chair, rubbed his hands together, smacked his lips and said, "I love a challenge!" The other, also confronting the hard problems, looked up at the experimenter and approvingly declared, "I was *hoping* this would be informative!" Predictably, the students with this attitude outperformed their cohorts in these studies.

Two Views of Intelligence

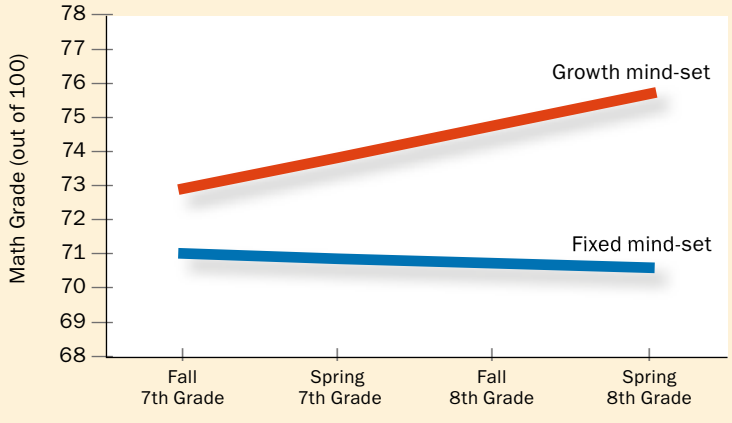
Several years later I developed a broader theory of what separates the two general classes of learners—helpless versus mastery-oriented. I realized that these different types of students not only explain their failures differently, but they also hold different "theories" of intelligence. The helpless ones believe that intelligence is a fixed trait: you have only a certain amount, and that's that. I call this a "fixed mind-set." Mistakes crack their self-confidence because they attribute errors to a lack of ability, which they feel powerless to change. They avoid challenges because challenges make mistakes more likely and looking smart less so. Like Jonathan, such children shun effort in the belief that having to work hard means they are dumb.

The mastery-oriented children, on the other hand, think intelligence is malleable and can be developed through education and hard work. They want to learn above all else. After all, if you believe that you can expand your intellectual skills, you want to do just that. Because slipups stem from a lack of effort or acquirable skills, not fixed ability, they can be remedied by perseverance. Challenges are energizing rather than intimidating; they offer opportunities to learn. Students with such a growth mind-set, we predicted, were destined for greater academic success and were quite likely to outperform their counterparts.

We validated these expectations in a study published in early 2007. Psychologists Lisa Blackwell, then at Columbia University, and Kali H. Trzesniewski, then at Stanford University, and I monitored 373 students for two years during the transition to junior high school, when the work gets more

Mind-set and Math Grades

Students who believed that intelligence is malleable (*growth mind-set line*) earned higher math grades in the fall of seventh grade than those who believed in static intelligence (*fixed mind-set line*), even though the two groups had equivalent math achievement test scores in the sixth grade. The grades of the growth mind-set group then improved over the next two years, whereas the grades of the fixed mind-set students declined.



FROM "IMPLICIT THEORIES OF INTELLIGENCE PREDICT ACHIEVEMENT ACROSS AN ADOLESCENT TRANSITION: A LONGITUDINAL STUDY AND AN INTERVENTION," BY L. S. BLACKWELL, K. H. TRZESNIEWSKI AND C. S. DWECK, IN *CHILD DEVELOPMENT*, VOL. 78, NO. 1; JANUARY/FEBRUARY 2007

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A for Effort

According to a survey we conducted in the mid-1990s, 85 percent of parents believed that praising children's ability or intelligence when they perform well is important for making them feel smart. But our work shows that praising a child's intelligence makes a child fragile and defensive. So, too, does generic praise that suggests a stable trait, such as "You are a good artist." Praise can be very valuable, however, if it is carefully worded. Praise for the specific process a child used to accomplish something fosters motivation and confidence by focusing children on the actions that lead to success. Such process praise may involve commending effort, strategies, focus, persistence in the face of difficulty, and willingness to take on challenges. The following are examples of such communications:

You did a good job drawing. I like the detail you added to the people's faces.

You really studied for your social studies test. You read the material over several times, outlined it and tested yourself on it. It really worked!

I like the way you tried a lot of different strategies on that math problem until you finally got it.

That was a hard English assignment, but you stuck with it until you got it done. You stayed at your desk and kept your concentration. That's great!

I like that you took on that challenging project for your science class. It will take a lot of work—doing the research, designing the apparatus, making the parts and building it. You are going to learn a lot of great things.

Parents and teachers can also teach children to enjoy the process of learning by expressing positive views of challenges, effort and mistakes. Here are some examples:

Boy, this is hard—this is fun.

Oh, sorry, that was too easy—no fun. Let's do something more challenging that you can learn from.

Let's all talk about what we struggled with today and learned from. I'll go first.

Mistakes are so interesting. Here's a wonderful mistake. Let's see what we can learn from it. —*C.S.D.*

difficult and the grading more stringent, to determine how their mind-sets might affect their math grades. At the beginning of seventh grade, we assessed the students' mind-sets by asking them to agree or disagree with statements such as "Your intelligence is something very basic about you that you can't really change." We then assessed their beliefs about other aspects of learning and looked to see what happened to their grades.

As we had predicted, the students with a growth mind-set felt that learning was a more important goal in school than getting good grades. In addition, they held hard work in high regard, believing that the more you labored at something, the better you would become at it. They understood that even geniuses have to work hard for their great accomplishments. Confronted by a setback such as a disappointing test grade, students with a growth mind-set said they would study harder or try a different strategy for mastering the material.

The students who held a fixed mind-set, however, were concerned about looking smart with less regard for learning. They had negative views of effort, believing that having to work hard at something was a sign of low ability. They thought that a person with talent or intelligence did not need to work hard to do well. Attributing a bad grade to their own lack of ability, those with a fixed mind-set said that they would study *less* in the future, try never to take that subject again and consider cheating on future tests.

Such divergent outlooks had a dramatic impact on performance. At the start of junior high, the math achievement test scores of the students with a growth mind-set were comparable to those of students who displayed a fixed mind-set. But as the work became more difficult, the students with a growth mind-set showed greater persistence. As a result, their math grades overtook those of the other students by the end of the first semester—and the gap between the

AGE FOTOSTOCK

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two groups continued to widen during the two years we followed them [*see box on page 79*].

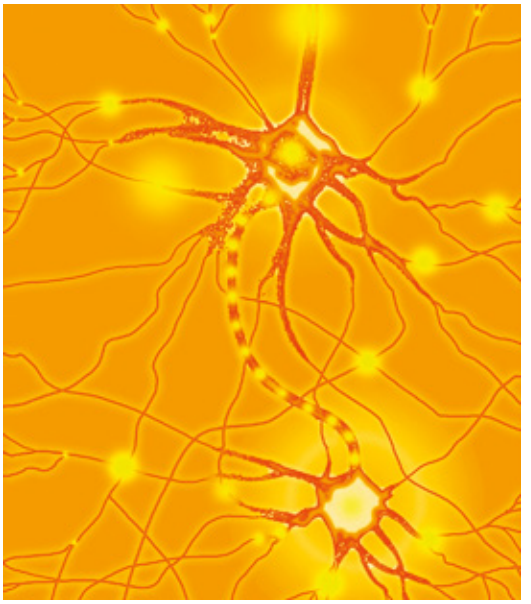
Along with psychologist Heidi Grant Halvorson, now at Columbia, I found a similar relation between mind-set and achievement in a 2003 study of 128 Columbia freshman premed students who were enrolled in a challenging general chemistry course. Although all the students cared about grades, the ones who earned the best grades were those who placed a high premium on learning rather than on showing that they were smart in chemistry. The focus on learning strategies, effort and persistence paid off for these students.

Confronting Deficiencies

A belief in fixed intelligence also makes people less willing to admit to errors or to confront and remedy their deficiencies in school, at work and in their social relationships. In a study published in 1999 of 168 freshmen entering the University of Hong Kong, where all instruction and coursework are in English, three Hong Kong colleagues and I found that students with a growth mind-set who scored poorly on their English proficiency exam were far more inclined to take a remedial English course than were low-scoring students with a fixed mind-set. The students with a stagnant view of intelligence were presumably unwilling to admit to their deficit and thus passed up the opportunity to correct it.

A fixed mind-set can similarly hamper communication and progress in the workplace by leading managers and employees to discourage or ignore constructive criticism and advice. Research by psychologists Peter Heslin, now at the University of New South Wales in Australia, Don VandeWalle of Southern Methodist University and Gary Latham of the University of Toronto shows that managers who have a fixed mind-set are less likely to seek or welcome feedback from their employees than are managers with a growth mind-set. Presumably, managers with a growth mind-set see themselves as works-in-progress and understand that they need feedback to improve, whereas bosses with a fixed mind-set are more likely to see criticism as reflecting their underlying level of competence. Assuming that other people are not capable of changing either, executives with a fixed mind-set are also less likely to mentor their underlings. But after Heslin, VandeWalle and Latham gave managers a tutorial on the value and principles of the growth mind-set, supervisors became more willing to coach their employees and gave more useful advice.

Mind-set can affect the quality and longevity of personal relationships as well, through people's willingness—or unwillingness—to deal with difficulties. Those with a fixed mind-set are less likely than those with a growth mind-set to broach problems in their relationships and to try to solve them, according to a 2006 study I conducted with psychologist Lara Kammrath, now at Wake Forest University. After all, if you think that human personality traits are more or less fixed, relationship repair seems largely futile. Individuals who believe people can change and grow, however, are more confident that confronting concerns in their relationships will lead to resolutions.



In tutorials that advance a growth mind-set, students discover that learning promotes the formation of stronger connections between neurons in the brain.

MEHAU KULYK *SPL/Photo Researchers, Inc.*

Proper Praise

How do we transmit a growth mind-set to our children? One way is by telling stories about achievements that result from hard work. For instance, talking about mathematical geniuses who were more or less born that way puts students in a fixed mind-set, but descriptions of great mathema-

THE AUTHOR

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ticians who fell in love with math and developed amazing skills engenders a growth mind-set, our studies have shown. People also communicate mind-sets through praise [*see box on page 80*]. Although many, if not most, parents believe that they should build up children by telling them how brilliant and talented they are, our research suggests that this is misguided.

In studies involving several hundred fifth graders published in 1998, for example, psychologist Claudia M. Mueller, now at Stanford, and I gave children questions from a nonverbal IQ test. After the first 10 problems, on which most children did fairly well, we praised them. We praised some of them for their intelligence: "Wow … that's a really good score. You must be smart at this." We commended others for their process: "Wow … that's a really good score. You must have worked really hard."

We found that intelligence praise encouraged a fixed mind-set more often than did pats on the back for effort. Those congratulated for their intelligence, for example, shied away from a challenging assignment—they wanted an easy one instead—far more often than the kids applauded for their process. (Most of those lauded for their hard work wanted the difficult problem set from which they would learn.) When we gave everyone hard problems anyway, those praised for being smart became discouraged, doubting their ability. And their scores, even on an easier problem set we gave them afterward, declined as compared with their previous results on equivalent problems. In contrast, students praised for their hard work did not lose confidence when faced with the harder questions, and their performance improved markedly on the easier problems that followed [*see box on opposite page*].

Making Up Your Mind-set

In addition to encouraging a growth mind-set through praise for effort, parents and teachers can help children by providing explicit instruction regarding the mind as a learning machine. Blackwell, Trzesniewski and I designed an eight-session workshop for 91 students whose math grades were declining in their first year of junior high. Forty-eight of the students received instruction in study skills only, whereas the others attended a combination of study skills sessions and classes in which they learned about the growth mind-set and how to apply it to schoolwork.

In the growth mind-set classes, students read and discussed an article entitled "You Can Grow Your Brain." They were taught that the brain is like a muscle that gets stronger with use and that learning prompts neurons in the brain to grow new connections. From such instruction, many students began to see themselves as agents of their own brain development. Students who had been disruptive or bored sat still and took note. One particularly unruly boy looked up during the discussion and said, "You mean I don't have to be dumb?"

As the semester progressed, the math grades of

Chemist Marie Curie (*left*) and inventor Thomas A. Edison (*right*) developed their genius through passion and tremendous effort.

BETTMANN/CORBIS (*Curie* and *Edison*)

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the kids who learned only study skills continued to decline, whereas those of the students given the growth-mind-set training stopped falling and began to bounce back to their former levels. Despite being unaware that there were two types of instruction, teachers reported noticing significant motivational changes in 27 percent of the children in the growth mind-set workshop as compared with only 9 percent of students in the control group. One teacher wrote: "Your workshop has already had an effect. L [our unruly male student], who never puts in any extra effort and often doesn't turn in homework on time, actually stayed up late to finish an assignment early so I could review it and give him a chance to revise it. He earned a B+. (He had been getting Cs and lower.)"

Other researchers have replicated our results. Psychologists Catherine Good, now at Baruch College, Joshua Aronson of New York University and Michael Inzlicht, now at the University of Toronto, reported in 2003 that a growth mind-set workshop raised the math and English achievement test scores of seventh graders. In a 2002 study Aronson, Good (then a graduate student at the University of Texas at Austin) and their colleagues found that college students began to enjoy their schoolwork more, value it more highly and get better grades as a result of training that fostered a growth mind-set.

We have now encapsulated such instruction in an interactive computer program called Brainology. Its five modules teach students about the brain—what it does and how to make it work better. In a virtual brain lab, users can click on brain regions to determine their functions or on nerve endings to see how connections form or strengthen when people learn. Users can also advise virtual students with problems as a way of practicing how to handle schoolwork difficulties; additionally, users keep an online journal of their study practices.

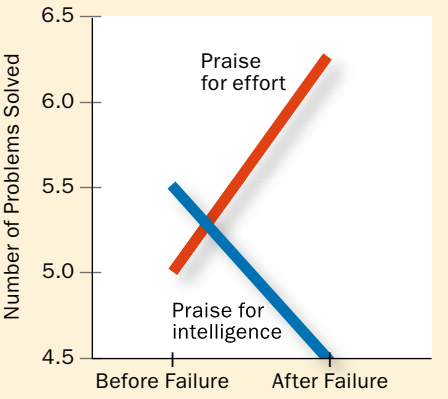
New York City seventh graders who tested Brainology told us that the program had changed their view of learning and how to promote it. One wrote: "My favorite thing from Brainology is the neurons part where when u [sic] learn something there are connections and they keep growing. I always picture them when I'm in school." A teacher said of the students who used the program: "They offer to practice, study, take notes, or pay attention to ensure that connections will be made."

Teaching children such information is not just a ploy to get them to study. People may well differ in intelligence, talent and ability. And yet research is converging on the conclusion that great accomplishment, and even what we call genius, is typically the result of years of passion and dedication and not something that flows naturally from a gift. Mozart, Edison, Curie, Darwin and Cézanne were not simply born with talent; they cultivated it through tremendous and sustained effort. Similarly, hard work and discipline contribute more to school achievement than IQ does.

Such lessons apply to almost every human endeavor. For instance, many young athletes value talent more than hard work and have consequently become unteachable. Similarly, many people accomplish little in their jobs without constant praise and encouragement to maintain their motivation. If we foster a growth mind-set in our homes and schools, however, we will give our children the tools to succeed in their pursuits and to become productive workers and citizens. M

The Effects of Praise

Children praised for their intelligence solved significantly fewer problems after a failure than they had before encountering difficulty. In contrast, children praised for their effort solved *more* problems after their brush with adversity than they had before it.



FROM "PRAISE FOR INTELLIGENCE CAN UNDERMINE CHILDREN'S MOTIVATION AND PERFORMANCE," BY C. M. MUELLER AND C. S. DWECK, IN *JOURNAL OF PERSONALITY AND SOCIAL PSYCHOLOGY*, VOL. 75, NO. 1: JULY 1998

MORE TO EXPLORE

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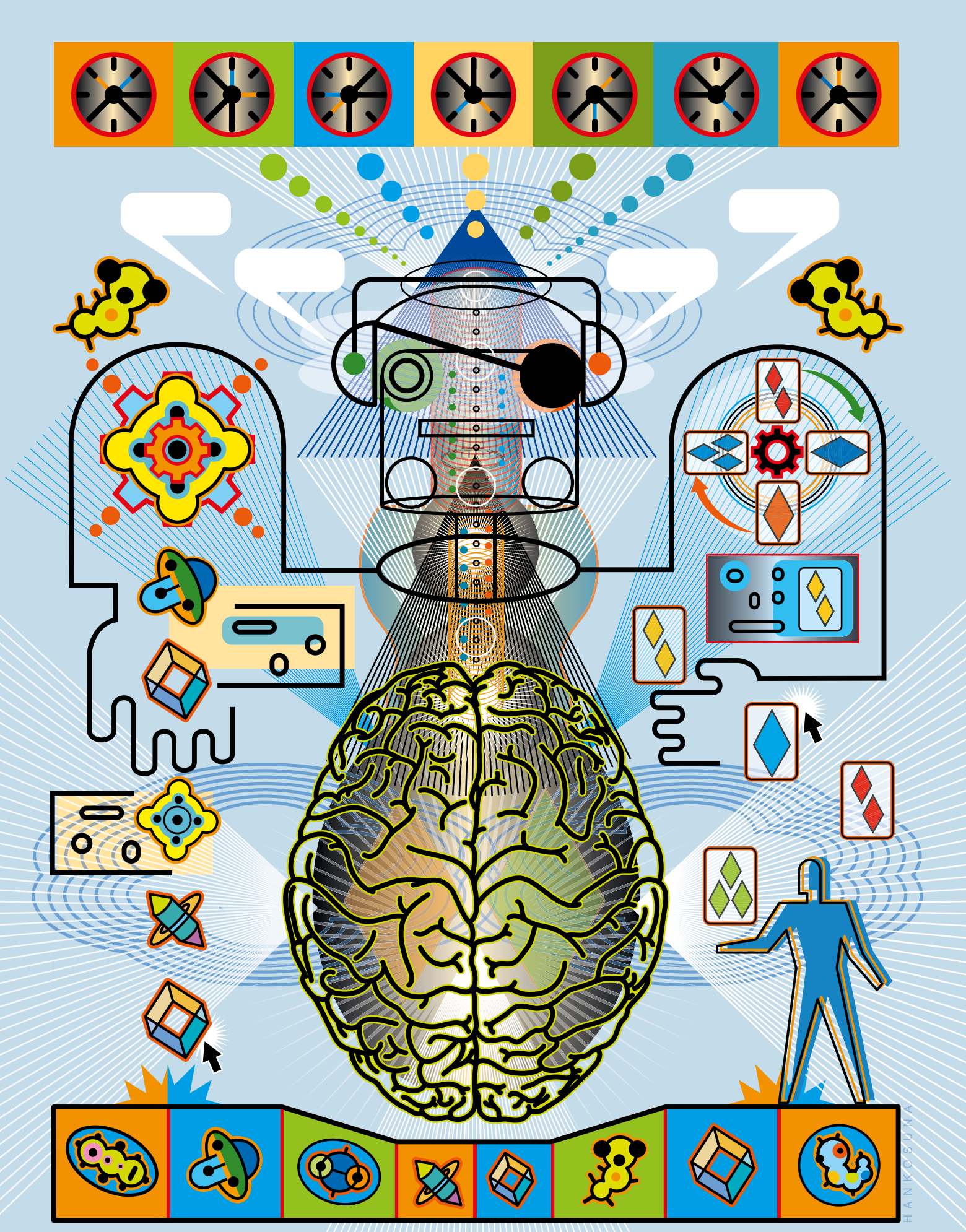

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CALISTHENICS FOR A CHILD'S MIND

SCIENTISTS HAVE CONCOCTED MENTAL FITNESS REGIMENS TO STRENGTHEN WEAK THINKING SKILLS IN STUDENTS—IN EFFECT, MAKING KIDS SMARTER

BY INGRID WICKELGREN

A mop of light brown hair shakes as a slender nine-year-old boy named Jack bangs furiously at his keyboard. Jack's eyes are fixed on a clock with six hands, which denote the month, day, hour, minute, second and 60th of a second. As soon as he types 10:28:2:14:56:32, a new clock appears, and he hammers out another set of numbers. An affable 14-year-old student named Marti had just taught me the exercise, and I guessed I could have solved one of these clocks in a few minutes. Jack was finishing one every seven seconds.

Jack's incessant clacking is virtually the only sound in this small classroom of eight- and nine-year-olds. The others work silently. One or two wear an eye patch, copying symbols onto grids. A dark-haired girl listens through headphones to a list of words she must memorize and repeat to a teacher. One boy stares at a Norman Rockwell painting; his job is to extract its main idea and write it down.

Jack, his long red sleeves poking out from under a blue school T-shirt with the initials "EAS," cracks clock codes for 35 minutes almost nonstop. As with others at Eaton Arrowsmith School, a private facility for the learning disabled on the second floor of a building on the campus of the University of British Columbia in Vancouver, Jack attends six periods of brain exercises, among them reading clocks, copying symbols, tracing complex

ILLUSTRATION BY HANK OSUNA

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In a classroom at Eaton Arrowsmith School in Vancouver, B.C., students work independently on computerized and paper-based exercises designed to bolster basic mental processes such as memory and reasoning.

designs, memorizing patterns and performing mental arithmetic. Jack has one period of English and one period of mathematics, but none of his other classes resemble those in an ordinary school.

Arrowsmith students do not learn about the branches of government or genres of literature. Their time is devoted instead to fortifying mental processes such as attention, memory and reasoning. For decades psychologists have thought that such fundamental thinking capacities were fixed. In research circles, evidence is mounting that they may not be.

The Arrowsmith program is intensive, requiring students to dedicate 80 percent of their day for three to four years to brain remediation before returning to regular school. Although the school boasts a number of success stories, support for its regimen's effectiveness is mainly anecdotal. Nevertheless, a commitment to its style of brain fitness for children is gathering steam in the scientific, clinical and even mainstream educational communities.

A small collection of brain-training workouts has emerged from neuroscience and psychology laboratories in recent years, and several are now being marketed and sold. Some build working (short-term) memory, a kind of mental whiteboard that is linked to intelligence. Others target basic number sense, for math, or sound perception, for reading. Another trains reasoning.

FAST FACTS

BEEFING UP YOUNG BRAINS

1. Psychologists have long believed that thinking capacities such as attention, memory and reasoning were fixed, but evidence is mounting that they are not.
2. A smattering of brain-training workouts has emerged from neuroscience and psychology laboratories, and several of the programs are now being marketed and sold.
3. In many cases, the brain workouts are aimed at kids with learning problems, but some educators are offering them to all children as part of regular instruction.

In many cases, the tools are aimed at learning problems such as dyslexia, dyscalculia or attention-deficit hyperactivity disorder (ADHD). But some educators are starting to offer brain training to the general school population. "I see the technology as making it possible to individualize training and learning for everybody," says psychologist Allyson P. Mackey of the Massachusetts Institute of Technology. "Even kids performing fairly well might have a weakness, and if you patch that up, they would perform much better."

The extent to which children can overcome intellectual deficits or raise their IQ through mental calisthenics is largely unknown. Although data suggest that the training can be useful, it does not always work. In addition, researchers are only now beginning to explore whether the measured gains in their thinking skills translate into academic achievement.

Still, many scientists and educators now believe that with the proper tools, students can increase their intellectual capacity—an idea that could transform lives. "The question is: What are we capable of as human beings?" asks Howard Eaton, a learning disabilities specialist who founded Eaton Arrowsmith. The notion that people can fundamentally alter their brains, he says, "changes your whole perspective on human possibility."

Levers for Learning

Of course, school has long been based on the premise that the brain is flexible: learning new information and skills involves changes at the neural level. Still, people have assumed that a person's *capacity* to learn is fairly stable. Part of this capacity lies in executive functions, a set of faculties governed by a structure called the prefrontal cortex that sits just behind the forehead. These faculties

COURTESY OF SANDRA HEUSEL *Eaton Educational Group*

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"I SEE THE TECHNOLOGY AS MAKING IT POSSIBLE TO INDIVIDUALIZE TRAINING AND LEARNING FOR EVERYBODY," SAYS ONE PSYCHOLOGIST.

are working memory, cognitive flexibility—the ability to find alternative solutions to problems and shift from one idea or action to another—and self-regulation, the ability to inhibit competing or inappropriate actions.

School is not traditionally designed to alter executive function, nor is it typically structured to tweak basic math ability or facility for listening to language. It does not do these things in part because people assumed those basics of the brain were immovable.

Yet it is no secret that environment can have a powerful effect on intellectual capacity. Stressful circumstances such as those that accompany poverty, for example, can virtually shut down executive functions. A child's socioeconomic class can also strongly influence language skills that are fundamental to reading. "For a four- or five-year-old, the difference in language exposure between a child from a low socioeconomic class and one from a high socioeconomic class can be as much as 30 million words," says neuroscientist William M. Jenkins, chief scientific officer at Scientific Learning in Oakland, Calif.

In that light, the notion that tailored coaching could *boost* a child's potential to learn is less difficult to fathom. In recent years researchers have devised curricula designed to promote self-regulation, a skill essential to both academic success and social and emotional maturity. Meanwhile other scientists have set out to design interventions aimed more squarely at an individual child's intellectual capacity.

One critical lever on intellect is working memory. Various cognitive skills depend on this mental scratch pad. Attention, in particular, entails mentally taking note of important information. "If you can't hold a plan in mind, you'll get distracted," says cognitive neuroscientist Torkel Klingberg of the Karolinska Institute in Stockholm.

In 1997 Klingberg was studying the neural basis of working memory when he came across a paper showing that kids with ADHD very often had limited working memory capacity. Although working memory was widely believed to be a static trait, Klingberg was radically optimistic about its pliability. "I thought of it as a muscle that could be trained," he recalls.

With attention deficits in mind, Klingberg and his colleagues created workouts for recalling locations—such as directions to a shopping mall—as well as verbal information. In some exercises, users try to reproduce the order in which an array of red bulbs or asteroids light up. As with all good training programs, these adapt to the child: as her performance improves, the game gets harder. At higher levels, the asteroids move, or the grid of lights rotates before the player has to recall the order. A verbal task requires remembering a series of digits and repeating it in reverse.

In a study published in 2005 by Klingberg's team, 22 kids aged seven to 12 who had severe attention problems played these games for 35 to 40 minutes a day for 25 days. The children improved significantly more on a standard assessment of working memory than did 22 kids with ADHD who

COURTESY OF NCS PEARSON

In Cogmed working memory training, players try to click on asteroids (*left*) in a sequence that matches the one they just saw. They also punch numbers on a keypad (*right*) in the order opposite to the one they just heard.

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used much easier versions of the same games. In addition, parents of the trained youths said their children became more attentive. Based on such results, Klingberg founded a company called Cogmed, now owned by Pearson, the education firm, to market the software. (Klingberg is no longer associated with Cogmed.)

AMONG KIDS WHO SCORE IN THE LOWEST 10 PERCENT ON WORKING MEMORY TESTS, MORE THAN FOUR FIFTHS HAVE ACADEMIC TROUBLES.

Scientists have since garnered additional support for these games as remedies for ADHD. In 2010 psychologist William B. Benninger of Ohio State University and his colleagues found that children and adolescents with ADHD who did the drills at home became more attentive, better organized and had fewer symptoms, according to their parents, than those who did not exercise their recall. In 2012 psychologist Julie B. Schweitzer of the University of California, Davis, School of Medicine and her associates reported that the training significantly reduced "off-task" behavior in 12 children with ADHD while doing schoolwork—that is, looking away from a worksheet, a more real-world measure of focus.

Playing games such as Rush Hour (*above*) that require reasoning upped the IQ scores of kids from a low-income community.

Working memory can have a profound effect on learning in general. Among children who score in the lowest 10 percent of the population on working memory tests, more than four fifths have considerable problems in reading or math, or both. From a test of 345 children between the ages of eight and 11, psychologist Darren L. Dunning, now at the University of East Anglia in England, and his colleagues identified 42 children who fell in the lowest 15 percent in working memory ability. They assigned 22 of them to intensive, in-school Cogmed training for five to seven weeks; the others received a less taxing version of the program. By the end of the instruction, the children who did the more intensive exercises showed a big boost in all aspects of working memory, whereas the other kids reaped only minimal gains. Moreover, six months later the kids who got the real training scored significantly higher on a standardized test of mathematical reasoning than they had at the beginning of the trial, indicating that they used their trained brains to learn more math.

THE AUTHOR

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Getting Out of a Jam

Another critical component of academic success is reasoning, the capacity to think logically, connect ideas and solve problems in novel situations. Reasoning is a higher-level skill that depends on executive functions such as working memory and attention. The clock puzzles Jack solves so expertly are supposed to train reasoning by building a child's understanding of relations such as those between the different hands on a clock.

Several years ago M.I.T.'s Mackey, then a psychology graduate student at the University of California, Berkeley, wanted to see if she could sharpen reasoning in disadvantaged children. Collaborating with her colleague, psychologist Silvia A. Bunge, Mackey selected computer and commercial board games that rely heavily on reasoning. In one board game, called Rush Hour, players need to figure out how to get a car to escape a traffic jam while still obeying the laws of the road. Other games depended on logic or on integrating different pieces of information. They asked 17 students, aged seven to 10, from an elementary school in a high-poverty neighborhood in Oakland, Calif., to play the games for an hour a day, two days a week, for eight weeks. Another 11 students played games that taxed processing speed—how quickly they could make sense of information—instead.

The kids who played the reasoning games saw their scores jump by more than 30 percent on a standard test of that skill—and their IQ scores rose 10 points on average. The students who played games that exercised processing speed upped their ranking on a test of that ability by 30 percent. "We were really surprised at how big the gains were," Mackey says.

She is now trying to reproduce her results in a larger sample of kids at risk for school failure and determine whether the training translates into gains

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in academic achievement. "If we can show these kinds of games lead to better test scores, we've taken a huge step forward," Mackey says.

Five Dots or Six?

Computerized training programs can bolster basic math ability, too. Doing mental math depends heavily on working memory, which we use to hold and manipulate numbers. One Arrowsmith exercise involves adding one small number to the next as the digits appear sequentially, keeping a running total, and reporting the sum at the end.

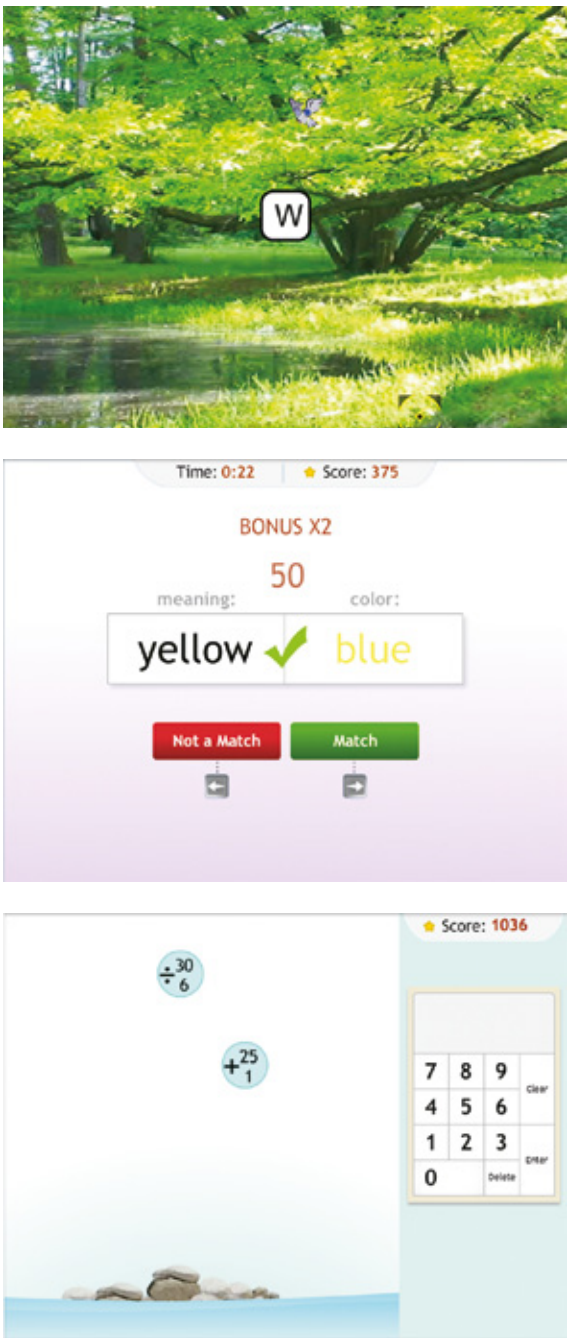
Other programs train number sense, a basic sense of quantity that enables us to immediately compare, say, the number of dots in two different arrays or subtract or add dots. Scientists have tied this sense to a location in the brain: a narrow indentation on its surface called the intraparietal sulcus. Without a well-developed sense of number, children will have trouble with math and may develop dyscalculia, a mathematical learning disability that afflicts up to 7 percent of the school-aged population. A nine-year-old with dyscalculia might, for example, confuse five dots with six or be unable to say whether 50 is greater or less than 100.

Several years ago neuroscientist Stanislas Dehaene of the French National Institute of Health and Medical Research and his colleagues created a Web-based game called Number Race, in which players compare quantities of dots and associate them with number symbols and learn some basic addition and subtraction facts. In 2006 the researchers reported that 15 seven- to nine-year-olds with dyscalculia who played Number Race got somewhat better at comparing numbers, making quick visual assessments of quantity and subtracting one-digit numbers [see "How to Build a Better Learner," by Gary Stix, on page 68].

Three years later the researchers tested the software on younger children at risk for math difficulties: 53 French kindergartners from low socioeconomic backgrounds. Some of the children played Number Race for six 20-minute sessions while others used a commercially available reading program, after which the kids switched tasks. Number Race, but not the reading software, improved the kids' ability to compare numbers represented as symbols, suggesting that the program honed the ability to connect number symbols to quantity. The team has since developed a more advanced game, called Number Catcher, that exercises basic calculation skills and represents numbers in different ways.

Lumosity, a company based in San Francisco, offers a suite of brain-training games aimed at various capacities, including several related to math. One involves arithmetic problems that appear in falling raindrops that must be solved before the drops splash into water at the bottom of the screen. In another, users compare the value of mathematical expressions presented in pairs. A third exercises problem solving. Players deduce the rule—"blue," say, or "animals"—behind the sorting of words or objects.

Such drills have shown promise in boosting math proficiency in children with inborn impediments to learning the subject. In a 2011 pilot study psychiatrist Shelli R. Kesler of Stanford University



Lumosity games target core thinking skills. Spot the bird before it vanishes while remembering the letter (*top*) to train your focus. Compare the word on the left with the color on the right (*middle*) to stretch your cognitive flexibility. Type the answers before the drops hit the water (*bottom*) to tune your problem-solving ability.

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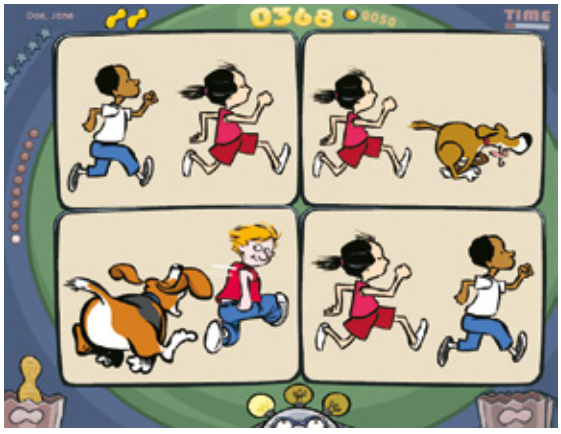
and her colleagues found that playing these games 20 minutes a day for six weeks ameliorated characteristic math-related deficiencies in 16 girls who had a genetic condition called Turner syndrome. After the training, the girls scored significantly higher on tests of number sense, processing speed and cognitive flexibility. Their knowledge of math facts and calculation ability also improved to a lesser extent.

Sounding It Out

As with math, reading involves a complex set of intellectual capacities, including reasoning and executive skills. Dyslexia, a reading disability in which the brain has trouble recognizing and processing words, afflicts 5 to 17 percent of children. In the early 1990s neuroscientist Paula Tallal of Rutgers University hypothesized that a root cause in many cases was auditory, specifically, a deficit in detecting rapid changes in similar sounds, such as "da" and "ba." Such difficulties, she argued, prevented children from acquiring good language skills, leading to dyslexia.



A program called Fast ForWord Language asks users to distinguish sounds such as "ada" and "aba" by choosing the acorn that uttered the target phoneme (*left*) and to parse sentences such as "The girl is chasing the dog" by clicking on the picture the sentence describes (*right*).

In 1996 Tallal and neuroscientist Michael Merzenich, now an emeritus professor at the University of California, San Francisco, founded Scientific Learning to develop computer software to correct auditory-processing problems in children with reading difficulties. The program, called Fast ForWord Language, helps children hear and discriminate phonemes by first slowing them down and emphasizing certain rapidly changing parts of speech, Jenkins says. Then it gradually speeds up and softens the emphasis. The software also morphs the sounds, making them more or less similar, depending on a child's proficiency.

Several small studies indicate that the program is helpful. In 2007 neuroscientist Nadine Gaab of Harvard Medical School, along with Tallal, among other colleagues, reported significant improvement in language and reading skills in 22 children with dyslexia who used the program 20 minutes a day five days a week for eight weeks. They also saw in these youngsters increased activation in brain circuitry responsible for processing rapidly changing sounds. In a 2008 investigation neuroscientist Helen J. Neville of the University of Oregon and her colleagues found evidence that Fast ForWord Language improved the ability of children with and without language impairments to pay attention to auditory stimuli. The kids also showed gains in language comprehension.

Not all studies back up Fast ForWord's efficacy. In a 2011 meta-analysis (quantitative review) of six large studies, psychologist Charles Hulme of the University of York in England, and his colleagues concluded that the program had little effect on children's language or reading difficulties. The mixed results may reflect differences in how the software was tested, including the degree to which adults monitored its use and motivated children to engage with it. After all, kids who quit using the program out of frustration or boredom are unlikely to benefit. In addition, not all children with dyslexia suffer from auditory problems. Indeed, the latest versions of Fast ForWord drill executive functions, among other skills critical to reading proficiency. These exercises may reach a wider swath of the student population than the original program did.

Playing for IQ Points

Most of the current student brain-training programs are aimed primarily at those with diagnosable deficits. The several hundred U.S. schools that have adopted the Cogmed software, for example,

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typically offer it to students with attention deficits and other learning disabilities. More than 500 clinics in the U.S. and Canada also use Cogmed, primarily with clients who have ADHD.

Yet the programs are also trickling into the educational mainstream. Although Fast ForWord is geared toward kids with reading problems, many of the more than 3,000 schools that have the software include it as part of regular instruction. So far 14,000 students in more than 500 classrooms worldwide have played a suite of brain games offered through the Lumosity Education Access Program (LEAP), and more than a quarter of Lumosity.com online users are younger than 21. At least one private parochial school in New York City has made Cogmed software available to the kids in its fifth and sixth grades. "This isn't limited to students with learning difficulties," says Nicole F. Ng, a former teacher who now manages LEAP. "It applies to a healthy student who wants to improve his cognitive capabilities."

Some data hint that brain training could benefit the typical learner. In an unpublished study that was conducted by Ng and her colleagues, 949 students aged six to 18 years in 43 schools played 28 Lumosity games for an average of six hours total during a semester. These youths raised their scores on a battery of neuropsychological tests significantly more than did 443 students who did not perform the exercises. The more hours a student trained, the more he or she improved on skills such as memory, processing speed and reasoning. Students who spent at least 10 hours of training saw measurable benefits, Ng says. She is now leading two different studies in 70 schools to determine whether the cognitive benefits translate into improved academic performance.

In other studies, psychologist John Jonides of the University of Michigan and his colleagues have been able to raise the IQ scores of typical elementary and middle school children with their own working memory regimen, but that method does not always produce the intended improvement. It may be, therefore, that the training is sensitive to the circumstances.

Before arriving at Eaton Arrowsmith, Marti had struggled in regular school. "I'd be staying up so late trying to reread and understand," she told me in 2012. "I ended up crying because I was overwhelmed with homework." Marti has since graduated from the program, and her ninth grade report card in December 2012 displayed straight As. School officials have data on numerous children who, like Marti, have been helped by the curriculum.

Outside scientists often find the Arrowsmith approach intriguing but say it lacks rigorous scientific support. "I saw one kid doing math on a computer faster than I could do it," says Adele Diamond, a developmental cognitive neuroscientist at the University of British Columbia. But, she warns, "I'd like to see data that it helps." Indeed, one small, eight-month investigation of the school's curriculum led by educational psychologist Linda Siegel of the University of British Columbia failed to show that it significantly improved students' scores on a battery of cognitive and achievement tests. New data are likely forthcoming, however. Microsoft CEO Satya Nadella and his wife Anu are donating $100,000 for brain imaging and other research to evaluate the Arrowsmith program.

EVENTUALLY THE EDUCATIONAL COMMUNITY MAY SUPPORT ADDING AT LEAST A DOLLOP OF BRAIN FITNESS TO CHILDREN'S USUAL SCHOLASTIC FARE.

Science does increasingly suggest that the brain is far more supple than we once assumed. Eventually the educational community may decide that the data support the adding of at least a dollop of brain fitness to children's usual scholastic fare. Although no one knows exactly the form such training will take, putting children's mental muscles through the paces on a regular basis could lead to lasting benefits. "I envision improvement of cognitive skills as part of education much more than it is right now," Mackey says. M

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CAN WE KEEP GETTING SMARTER?

EVER RISING IQ SCORES SUGGEST THAT FUTURE GENERATIONS WILL MAKE US SEEM LIKE DIMWITS IN COMPARISON

BY TIM FOLGER

Thirty years ago James R. Flynn, a researcher at the University of Otago in New Zealand, discovered a phenomenon that social scientists still struggle to explain: IQ scores have been increasing steadily since the beginning of the 20th century. Flynn went on to examine intelligence-test data from more than two dozen countries and found that scores were rising by 0.3 point a year—three full points per decade. Nearly three decades of follow-up studies have confirmed the statistical reality of the global uptick, now known as the Flynn effect. And scores are still climbing.

"To my amazement, in the 21st century the increases are continuing," says Flynn, whose most recent book on the subject—*Are We Getting Smarter?*—was published in September 2012. "The latest data show the gains in America humming right along at the old rate of three tenths of a point a year."

One of the strangest aspects of the Flynn effect is its relentless monotony—it does not slow or stop and restart. It just moves steadily upward, "as if guided by an invisible hand," Flynn says. Joseph Rodgers, a psychologist now at Vanderbilt University, examined the test results of nearly 13,000 American students to see if he could detect the Flynn effect on more granular timescales. "We wondered if the students' scores would get better over a five- or 10-year period. Well, they get better over a one-year period," Rodgers says. "The increase is there, systematically, year by year by year. Kids born in 1989 do a little better than kids born in 1988."

The Flynn effect means that children will, on average, score about 10 points higher on IQ tests than their parents did. By the end of this century our descendants will have nearly a 30-point advantage over us—the difference between average intelligence and the top 2 percent of the population—*if* the Flynn effect continues. But can it continue? Will the trend go on indefinitely, leading to a future filled with people who would be considered geniuses by today's standards? Or is there some natural limit to the Flynn effect and to human intelligence?

The Modern Mind

Almost as soon as researchers recognized the Flynn effect, they saw that the ascending IQ scores were the result almost entirely of improved performances on specific parts of the most widely used intelligence tests. One such test, the Wechsler Intelligence Scale for Children, or WISC, has multiple sections, each of which assesses different skills. It would seem more natural to expect improvements

PHOTOGRAPH BY KEVIN VAN AELST

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in crystallized intelligence—the kind of knowledge picked up in school. That is not happening, however. Scores in the sections that measure skills in arithmetic and vocabulary levels have remained largely constant over time.

Most of the IQ gains come from just two subtests devoted to abstract reasoning [*see box on opposite page*]. One deals with "similarities" and poses questions such as "How are an apple and an orange alike?" A low-scoring answer would be "They're both edible." A higher-scoring response would be "They're both fruit," an answer that transcends simple physical qualities. The other subtest consists of a series of geometric patterns that are related in some abstract way, and the test taker must correctly identify the relation among the patterns.

A paradox of the Flynn effect is that tests such as these were designed to be completely nonverbal and culture-free measurements of what psychologists call fluid intelligence—an innate capacity to solve unfamiliar problems. Yet the Flynn effect clearly shows that something in the environment is having a marked influence on the supposedly culture-free components of intelligence in populations the world over. Psychologists Ainsley Mitchum of Florida State University and Mark Fox of the University of Richmond, who have made detailed studies of generational differences in performance on intelligence tests, suspect that our enhanced ability to think abstractly may be linked to a new flexibility in the way we perceive objects in the world.

"Everybody is familiar with the start 'button' on a computer screen, but it's not really a button," Mitchum says. "I was trying to explain to my grandmother how to turn her computer off, and I said, 'Well, you hit the start button and select shutdown.' She was banging the mouse on the screen."

Mitchum adds that his grandmother is not unintelligent. She did, however, grow up in a world where buttons were buttons, and phones certainly were not cameras. Many researchers, Flynn among them, argue that rising IQ scores do not reflect an increase in our raw brainpower. Rather the Flynn effect shows how *modern* our minds have become. Such tests require a facility with recognizing abstract categories and making connections among them. And that facility, Flynn says, has become more useful over the past century than at any previous time in human history.

"If you don't classify abstractions, if you're not used to using logic, you can't really master the modern world," Flynn says. "Alexander Luria, a Soviet psychologist, did some wonderful interviews with peasants in rural Russia in the 1920s. He would say to them, 'Where there is always snow, bears are always white. There is always snow at the North Pole. What color are the bears there?' They would say they had never seen anything but brown bears. They didn't think of a hypothetical question as meaningful."

The peasants were not stupid. Their world just required different skills. "I think the most fascinating aspect of this isn't that we do so much better on IQ tests," Flynn says. "It's the new light it sheds on what I call the history of the mind in the 20th century."

A naive interpretation of the Flynn effect quickly leads to some strange conclusions. Simply extrapolating the effect back in time, for example, would suggest that the average person in Great Britain in 1900 would have had an IQ of around 70 by 1990 standards. "That would mean that the average Brit was borderline mentally retarded and wouldn't have been able to follow the rules of cricket," says David Hambrick, a cognitive psychologist at Michigan State University. "And of course, that's absurd."

We may not be smarter than our forebears, but there is no doubt our minds have changed. Flynn believes the change began with the industrial revolution, which engendered mass education, smaller families, and a society in which technical and managerial jobs replaced agricultural ones. New professional classes emerged—engineers, electricians, industrial architects—and their positions demanded a mastery of abstract principles. Education, in turn, became the driver for still more innovation and social change, setting up an ongoing positive feedback loop.

Most researchers agree with Flynn's broad assessment that the industrial revolution and technological advances are responsible for his eponymous effect. Yet pinning down precise causes—which might allow for the design of educational or social policies to augment the effect—has been difficult. Improvements in education certainly account for part of the advances. As recently as the beginning of the 20th century, most Americans spent no more than seven years in school. Today about half of all adults have had at least some tertiary education.

Formal education, though, cannot entirely explain what is going on. Some researchers had assumed that

FAST FACTS

INCREASING INTELLIGENCE

1. IQ scores have been steadily rising for a century, a phenomenon now known as the Flynn effect.
2. The surge in scores comes from supposedly "culture-free" tests of intelligence such as pattern matching.
3. Researchers believe the effect has its root in the increasingly abstracted nature of modern life.
4. More advanced minds create technologies that, in turn, enhance intelligence still further, forging a feedback loop that shows no signs of abating.

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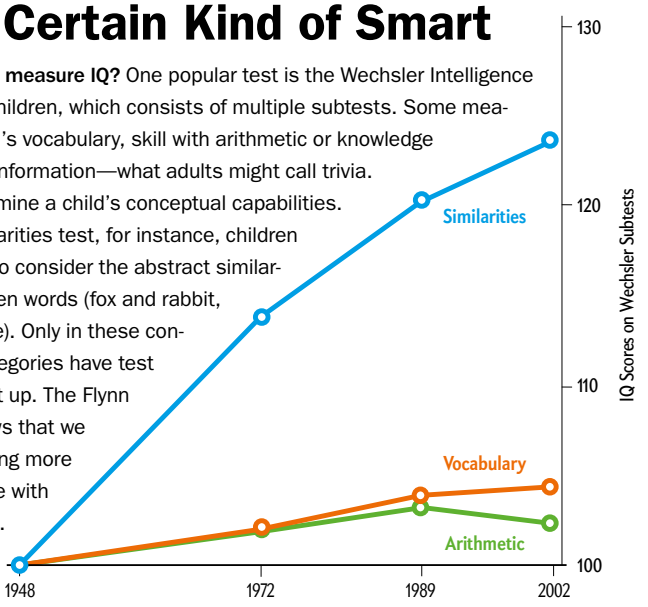
A Certain Kind of Smart

How do you measure IQ? One popular test is the Wechsler Intelligence Scale for Children, which consists of multiple subtests. Some measure a child's vocabulary, skill with arithmetic or knowledge of general information—what adults might call trivia. Others examine a child's conceptual capabilities. In the similarities test, for instance, children are asked to consider the abstract similarities between words (fox and rabbit, for instance). Only in these conceptual categories have test scores shot up. The Flynn effect shows that we are becoming more comfortable with abstraction.



most of the IQ increases seen over the 20th century might have been driven by gains at the left end of the intelligence bell curve among those with the lowest scores, an outcome that would likely be a consequence of better educational opportunities. A 2011 study by Jonathan Wai and Martha Putallaz of Duke University, however, looked at 20 years of data that comprise 1.7 million test results of fifth, sixth and seventh graders and found that the scores of the top 5 percent of the students were going up in perfect lockstep with the Flynn effect. Wai and Putallaz's results suggest that because the whole intelligence curve is shifting, the cultural forces behind the increase must be influencing everyone equally. The researchers speculate that the ubiquity of sophisticated video games—and even some television shows—may provide a training ground that enhances the problem-solving skills needed for IQ tests.

For Rodgers, the universality of the Flynn effect confirms the pointlessness of seeking a single cause: "There must be four or five dominant causes, any one of which can stand against fluxes or wanes in the other." Improved childhood nutrition, universal education, smaller families and the influence of educated mothers on their children are some of the most likely causes. "As long as two causes were in existence, even when something like the Second World War came along and caused the other two to disappear, the Flynn effect kept cranking along," Rodgers says.

Mental Evolution

Will IQ scores keep going up? One thing we can be sure of is that the world around us will continue to change, largely because of our own actions.

Flynn likes to use a technological analogy to describe the long-term interaction between mind and culture. "The speeds of automobiles in 1900 were absurdly slow because the roads were so lousy," he says. "You would have shaken yourself to pieces." But roads and cars co-evolved. When roads improved, cars did, too, and improved roads prompted engineers to design even faster cars.

Our minds and culture are locked in a similar feedback loop. We are creating a world where information takes forms and moves with speeds unimaginable just a few decades ago. Every gain in technology demands minds capable of accommodating the change, and the changed mind reshapes the world even more. The Flynn effect is unlikely to end during this century, presaging a future world where you and I would be considered woefully premodern and literal.

Of course, our minds are not only changing in ways that can be captured by IQ tests. "People are getting faster—I'm certain of this," Hambrick says. "A common practice in reaction-time research is to discard responses that are below about 200 milliseconds. It had been thought that 200 milliseconds is about the fastest that people can respond. But if you ask someone who has done this sort of research, they're having to discard more trials; people are getting faster. We text, we play video games, we do a lot more things that require really fast responses. I think once we have enough data, we'll be able to see a Flynn-like effect on measures of perceptual speed."

Maybe we should not be so surprised by the existence of something like the Flynn effect. Its absence would be more startling; it would mean we were no longer responding to the world we are creating. The Flynn effect itself is neither good nor bad—it is a symptom of our adaptability. If we are lucky, perhaps we will keep building a world that will make us smarter and smarter—one where our descendants will marvel at our simplicity. M

SOURCE: *ARE WE GETTING SMARTER? RISING IQ IN THE TWENTY-FIRST CENTURY*, BY JAMES R. FLYNN. CAMBRIDGE UNIVERSITY PRESS, 2012

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THE SOCIAL GENIUS OF ANIMALS

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NEW RESEARCH REVEALS THAT ANIMALS INTERACT IN SURPRISINGLY SOPHISTICATED WAYS

BY KATHERINE HARMON COURAGE

At the Thai Elephant Conservation Center, tucked away in the trees near Chiang Mai, a pair of Asian elephants gazes at two bowls of corn on the other side of a net. The corn is attached to a sliding platform, through which researchers have threaded a rope. The rope's ends lie on the elephants' side of the net. If only one elephant pulls an end, the rope slides out of the contraption. To bring the food within trunk's reach, the elephants have to do something only humans and other primates were thought to do: they must cooperate. Working in synchrony, each elephant grabs its end of the rope in its trunk and pulls, drawing the platform and the treats within reach.

Six pairs of these large animals succeeded in solving this double rope puzzle. A lone elephant would wait as long as 45 seconds for a partner to arrive, showing it knew it needed a buddy to get the job done. Psychologist Joshua M. Plotnik, now at Mahidol University in Thailand, and his colleagues, who documented these findings in 2011, also noticed that the elephant duos used different strategies for obtaining the food, suggesting that the animals had developed a deep understanding of social cooperation.

In the past century animals have repeatedly surpassed our expectations for their intellect. Koko the gorilla learned sign language; Alex the African grey parrot boasted a spoken vocabulary of more than 150 words, and even invertebrates such as the octopus have been seen using tools in the wild. Until the mid-20th century, we assumed only humans could use tools and learn meaningful pieces of a language. Sophisticated social skills such as cooperation were presumed to be way

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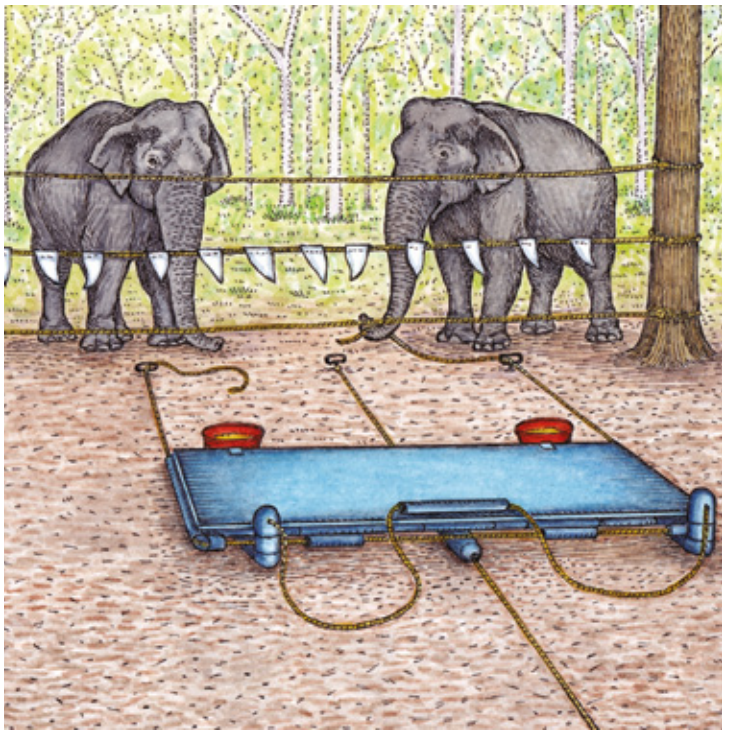

Pairs of elephants can work together—with each animal pulling on its end of a rope—to slide a platform, and two bowls of corn, within reach of their trunks.

beyond animals' cognitive reach. Only recently have researchers begun to realize the extent of animals' social intelligence, their ability to understand and learn from others.

The latest findings suggest that some animals are not only capable of creating social connections but that many use them for survival. As with people, some animals have social needs. They notice when another member of their species is distracted, and they are able to figure out an effective way to get its attention. Animals may teach one another important skills, such as how to use tools. Some critters can even deceive. Intuiting what others know enables them to trick one of their kind for personal gain. The animals described below have some of the most impressive social abilities in the animal kingdom. Studying how they interact is giving scientists new insight into what they know—and a glimpse at what might be the upper limits of animal intelligence.

FAST FACTS

SOCIAL CREATURES

1. Only recently have researchers realized the extent of animals' social intelligence—their ability to understand and learn from others.
2. Animals may teach one another important skills, such as how to use tools.
3. Some critters can deceive. Intuiting what others know enables an animal to trick another member of the same species for personal gain.

Making Connections

In our own lives, social intelligence might seem to play second fiddle to, say, the ability to do calculus or write a book. Individuals held up as modern geniuses, however, such as Stephen Hawking or the late Steve Jobs, have not only exceptional analytic skills but also an extraordinary ability to relate their ideas to a broader audience. These social skills are fundamental to our complex society. Without the ability to form a cohesive group, communicate ideas or collectively solve problems, humans could not have built the great pyramids or the first supercomputers.

Social skills require, first, a basic affinity for others. "You can't evolve all of the computational systems for social intelligence until you have that tendency that you want to be close to others," says biologist Louis Lefebvre of McGill University. Not all animals have this. Octopuses, for example, seek one another out only to procreate.

In contrast, zebra finches form monogamous pairs and congregate in groups. In a 2009 study the late biologist James Goodson of Indiana University Bloomington and his colleagues drilled down to the chemical essence of this social instinct: mesotocin, the bird equivalent of the human hormone oxytocin, which is implicated in bonding. When the researchers blocked mesotocin in the brains of the birds, they shrugged off their fellow finches. Females spent less than one third as much time near their same-sex cage mates after the treatment than before it. Extra doses of mesotocin had the opposite effect: the birds became even more social than they typically are.

Goodson and his colleagues also examined the biology of this hormone in other species of finches with different degrees of social affinity. The team found fewer receptors for mesotocin in key spots of the brain in species that were more territorial (less social) than the zebra finch—and more receptors in species that traveled in flocks. Scientists have identified similar patterns of brain chemicals and social preferences in many mammals. In prairie voles, for example, how mates bond with one another and their children is also associated with different levels of oxytocin and vasopressin, another hormone linked to social behavior and bonding.

Know Yourself—and Others

Good social graces also require a sense of the self as distinct from others. This primitive level of self-awareness allows animals to go beyond acting out a programmed set of behaviors for mating or for defense.

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Researchers test self-awareness by placing a visible mark on an animal and showing it a mirror. An animal passes the test if it appears to recognize that the dot is on its body as opposed to on the "other" animal in the mirror. It can signal this awareness, for example, by reaching toward the spot on its own body. Great apes, elephants, bottlenose dolphins, orcas and magpies have all passed, suggesting they have more social prowess than animals that simply flock or school together.

The second requirement for social networking is an understanding that others have different mental states—knowledge, desires, beliefs or intents—and that at any given moment another individual might be in a mental state that is different from the one you are in. This ability is called theory of mind. Psychologists often test its development in young children by having a child and an adult observe a researcher place an object in a specific location, say, a ball in a cup. The adult leaves the room, and the ball is moved. After the adult returns, a child with a mature theory of mind understands that the adult does not know the ball has moved, and he or she does not expect the adult to look for it in the new location. Similar theory-of-mind tests are difficult to conduct in animals because it is hard to communicate with them directly.

Nevertheless, we can glean hints from their physiology, such as the presence of so-called mirror neurons. These cells, which have been found in macaques and birds, swing into action when an animal sees another individual doing something. In humans, they are thought to exist in various brain regions, including the supplementary motor area, a small patch of tissue at the top of the head that helps to control movement. Because these cells' activity patterns mirror the behavior of others and to some extent reflect the movement's goal, they may enable animals to understand others' actions, possibly even their intentions. They might underlie the ability to learn motor actions by observation and also buttress a theory of mind.

Mirror neurons have not yet been discovered in dogs, but more than a decade ago psychologist Alexandra Horowitz of Barnard College collected behavioral data suggesting that dogs may have some version of a theory of mind. Over the course of 21 months Horowitz videotaped a random sampling of dogs at play in a San Diego dog park. When she analyzed the footage, she noticed some interesting behaviors that suggested dogs could be aware of another dog's perspective.

The dogs at the park varied how they signaled a desire to play depending on the other dog's position. If a prospective playmate was already facing it, the dog gave a visual signal—opening its mouth wide or bowing down into that familiar bottom-up play pose. But if the other dog was turned away and otherwise engaged, it might instead give its friend a little nip. "They seem to be noticing whether a dog they wanted to play with was ready to receive their play signal," Horowitz says. "They seem to be reacting to distinct cognitive states" of others. In a paper published in 2011 Horowitz posited that dogs possess at least a rudimentary theory of mind.

DOGS SEEM TO NOTICE WHETHER A DOG THEY WANT TO PLAY WITH IS READY TO RECEIVE THEIR PLAY SIGNAL. THEY SEEM TO REACT TO DISTINCT COGNITIVE STATES OF OTHER DOGS.

Consistent with the mirror neuron findings, many monkeys and some birds have demonstrated in their behavior at least some capacity for theory of mind. Monkeys, birds and dogs are exceptions, however. In most animal species, scientists have failed to see even a glimmer of evidence for this advanced social capacity.

Schools and Students

Among its many benefits, social intelligence confers the ability to distribute information. Scientists have long observed that herd animals can give warning signals if a predator is approaching; for example, a white-tailed deer may flash its conspicuous white tail, pointing it upward before bolting. Now, however, researchers are noticing that some animals that live in groups can teach one another rules of social engagement or how to create a tool.

Zebra fish, for example, seem to transmit sub-

THE AUTHOR

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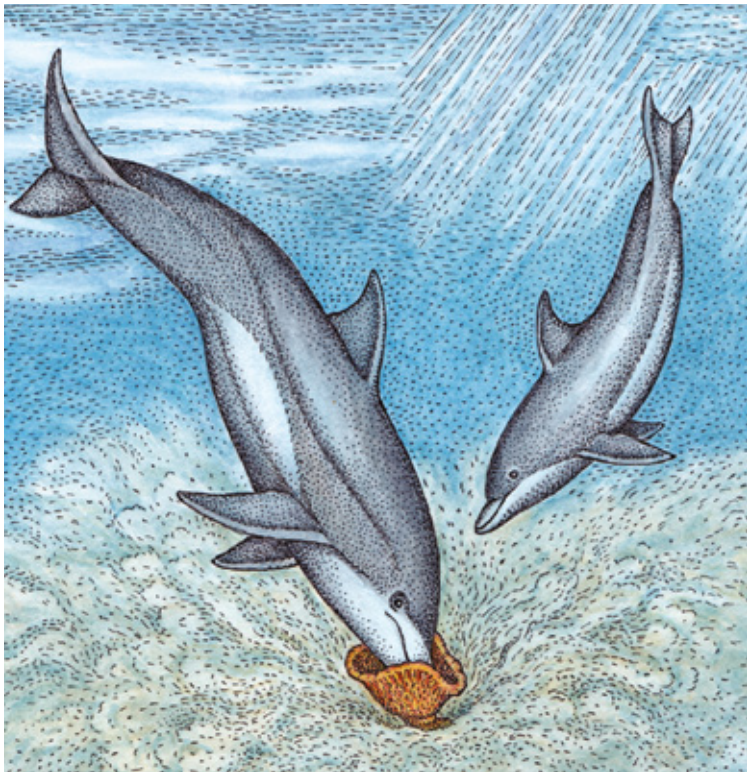
tle social cues to other members of their school. These small creatures can make an easy meal for larger fish in the wild, so they tend to be cautious of new objects. If they are reared in captivity, however, they show little fear of a moving object, swimming within close proximity of it.

A team of researchers led by biologist Sarah Zala of the Konrad Lorenz Institute of Ethology at the University of Veterinary Medicine in Vienna wanted to know if these fish would change their behavior if surrounded by others that acted differently. The group introduced some shy, wild zebra fish to more brazen domestic ones. The wild ones learned from their new acquaintances to be bolder when a moving object was introduced near the tank. Instead of swimming away from it, they joined their fearless new companions and ventured toward it. When the emboldened wild fish were separated from their new friends, they still bravely swam near novel things. The results, published in June 2012, indicate these fish had not just mindlessly followed the other fish but had learned a new behavior.

Dolphins can convey more intricate behaviors to others. One group of bottlenose dolphins in Australia uses a technique called sponging to find food. Biologist Janet Mann of Georgetown University and her colleagues saw the females sporting a sea sponge on their snout, a technique that seemed to allow the dolphins to push along the seafloor to look for fish and other food without hurting their nose. The scientists sampled DNA from these sponging mammals and compared it with DNA from area dolphins that did not use this tactic. They discovered that the sponging dolphins, but not the others, had a common maternal line. In a 2008 report of the findings, the researchers suggested that mothers in this particular group managed to teach this complex act to their daughters.

ROSIE DID NOT EAT AS MUCH, SLEEP AS SOUNDLY OR SHOW AS MUCH ENERGY AS USUAL FOR WEEKS AFTER HER MOTHER DIED, HINTING THAT THE CHIMPANZEE WAS IN MOURNING.



One study suggests that certain dolphin mothers teach their daughters to don a sea sponge on their snout to guard against injuries while they scour the seafloor for food.

Mother chimpanzees also use social learning to hand down wisdom to daughters. Young female chimps at the Gombe National Park in Tanzania are much handier at making tools to retrieve termites than are males. Adult females there use long twigs or stems to fish out termites, whereas males are more likely to kill larger game for their meals. In a study published in 2004, Elizabeth Lonsdorf of the Lincoln Park Zoo in Chicago and her colleagues found that the younger females spent more time with their mothers learning this skill than did the males, who were more likely to be playing—perfecting their social skills for later battles for dominance, mates and food.

Deception

Social learning can be a big advantage for a group or species, which can transmit the most successful strategies to others. Some animals, however, use their social awareness for personal gain by hiding information from potential competitors. A group led by psychologist Federica Amici, then at Liverpool John Moores University in England, trained low-ranking capuchin monkeys, long-tailed macaques and spider monkeys to unlock a box to obtain a food reward. When alone, these monkeys unlocked the box and indulged. But when a dominant monkey was around, the trained animals—especially

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the macaques—chose to forgo the hidden treat, ignoring the box so as not to reveal how to open it.

Some species of birds engage in a similar type of deceit, bolstering the argument that these animals might also possess some theory of mind. Whether in a laboratory or the wild, Western scrub jays are more likely to move their food stashes when other birds are around. In fact, lab experiments have shown that scrub jays will either move or pretend to move a newly caught worm if they think another bird might have seen them bury it. This behavior suggests some awareness of what the other individual knows and how they can protect their own interests. "Nonprimate species are thinking about these things in some very clever ways," says psychologist Laurie Santos of Yale University.

At least one of the cooperating Asian elephants in Plotnik's experiments also learned how to game the social system. The elephant, named Neua Un, figured out that instead of pulling on her side of the rope, she could stand on her end so it would not slip. Then she let the other elephant do all of the hard work. She also moved her trunk every now and then, as if to convince her partner that she, too, was pulling.

Emotional Aptitude

Of course, social IQ involves more than knowing how to get another person's attention or teaching the young new information and skills. A deeper social intelligence, one that allows for empathy and grief, is arguably the intangible, almost indescribable fiber that weaves us together. It is tied to our emotional well-being, and as new studies about longevity are showing, these rich social connections are important to our physical health as well. Although we might not be able to ask animals directly how they think and feel about others, we can watch them for clues.

In a 2010 paper psychologist James Anderson of the University of Stirling in Scotland and his colleagues described video footage of an adult female chimp named Rosie and her companions, who lived at the nearby Blair Drummond Safari and Adventure Park, reacting to the death of her elderly mother. Rosie did not eat as much, sleep as soundly or show as much energy as usual for weeks after her mother died, suggesting that the animal may have been in mourning. Other apes, including gorillas in the Democratic Republic of Congo's Virunga National Park, displayed similar patterns after the death of a parent or a peer.

Grief is not the only complex emotion observed in animals. Psychologist Frans B. M. de Waal of Emory University and his colleagues have shown that chimps prefer actions that will help peers to those that just benefit themselves, indicating that they are inclined toward altruism—a highly social quality once thought to be the exclusive domain of humans.

When a scrub jay spots another bird eyeing its food stash, it will move or pretend to move its edibles, indicating that these birds are cognizant of what their fellow jays know.

Social intelligence, as distinctive and intricate as it is, may not be easily separable from other forms of smarts such as problem-solving ability or knowledge of the world. For example, a scrub jay that moves its food stores to keep them secret has performed both social and nonsocial mental gymnastics, including, Lefebvre says, "sophisticated memory mechanisms and time travel [that project] future needs for food." Yet although brilliance very likely spans multiple axes, social cunning is one important—and often underappreciated—element. Indeed, the smarter we humans become about assessing the social intelligence of animals, the more closely related to us they may seem. M

MORE TO EXPLORE

- **Pan Thanatology.** James R. Anderson, Alasdair Gillies and Louise C. Lock in *Current Biology,* Vol. 20, No. 8, pages R349–R351; April 27, 2010.
- **Elephants Know When They Need a Helping Trunk in a Cooperative Task.** Joshua M. Plotnik et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 108, No. 12, pages 5116–5121; March 22, 2011.
- **Monkeys Represent Others' Knowledge but Not Their Beliefs.** Drew C. W. Marticorena et al. in *Developmental Science,* Vol. 14, No. 6, pages 1406–1416; November 2011.
- **Theory of Mind in Dogs? Examining Method and Concept.** Alexandra Horowitz in *Learning and Behavior,* Vol. 39, No. 4, pages 314–317; December 2011.

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TURBOCHARGING THE BRAIN

WILL A PILL AT BREAKFAST IMPROVE CONCENTRATION AND MEMORY—AND WILL IT DO SO WITHOUT LONG-TERM DETRIMENT TO YOUR HEALTH?

BY GARY STIX

The symbol H+ is the code sign used by some futurists to denote an enhanced version of humanity. The plus version of the human race would deploy a mix of advanced technologies, including stem cells, robotics, cognition-enhancing drugs, and the like, to overcome basic mental and physical limitations.

The notion of enhancing mental functions by gulping down a pill that improves attention, memory and planning—the very foundations of cognition—is no longer just a fantasy shared by futurists. The 1990s, proclaimed the decade of the brain by President George H. W. Bush, has been followed by what might be labeled "the century of the better brain."

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Obsession with cognitive enhancers is evidenced in news articles hailing the arrival of what are variously called smart drugs, neuroenhancers, nootropics or even "Viagra for the brain." From this perspective, an era of enhancement has already arrived. College students routinely borrow a few pills from a friend's Ritalin prescription to pull an all-nighter. Software programmers on deadline or executives trying to maintain a mental edge gobble down modafinil, a newer generation of pick-me-ups. Devotees swear that the drugs do more than induce the wakefulness of a caramel macchiato, providing instead the laserlike focus needed to absorb the nuances of organic chemistry or explain the esoterica of collateralized debt obligations.

An era of enhancement may also be advanced by scientists and drugmakers laboring to translate research on the molecular basis of cognition into pharmaceuticals meant specifically to improve mental performance—mainly for people suffering from dementias. But a drug that works for Alzheimer's or Parkinson's patients might inevitably be prescribed by physicians far more broadly in an aging population with milder impairments. Widely publicized debates over the ethics of enhancement have reinforced the sense that pills able to improve cognition will one day be available to us all.

Academic and news articles have asked whether cognitive enhancers already give some students an unfair advantage when taking college entrance exams or whether employers would step over the line if they required ingestion of these chemicals to meet a company's production deadlines.

But even as articles are published on the "boss turns pusher," doubts have arisen about the reality of drugs for strengthening brainpower. Do current drugs developed for attention problems or excessive sleepiness really allow a student to do better on an exam or an executive to perform flawlessly under sharp questioning from a board of directors? Will any drug that fiddles with basic brain functions ever be safe enough to be sold alongside nonprescription pain relievers and antacids? These questions are now provoking heated deliberations among neuroscientists, physicians and ethicists.

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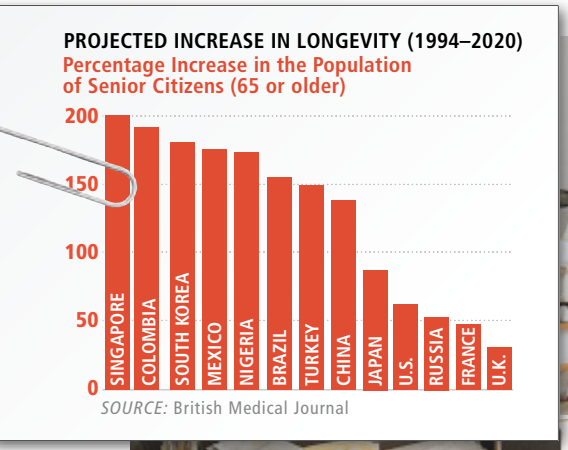
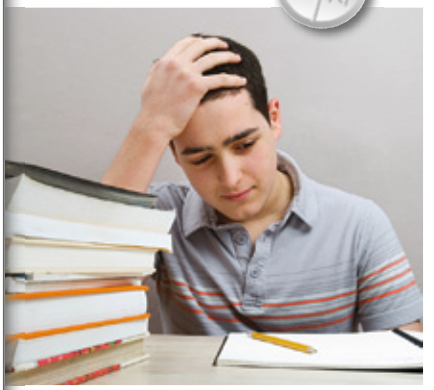
Why Enhance?

An aging population (*graph*), ubiquitous Internet pharmacies, and a workforce and student population strapped with deadlines and performance pressures (*photographs*) help to explain the fascination with cognition-enhancing drugs.





Ethical Dissonance

Arguments about safety, fairness and coercion aside, demand is indeed high for cognitive enhancers that are otherwise prescribed for conditions such as ADHD. Based on government data gathered in 2011, more than 2.7 million people in the U.S. had used prescription stimulants nonmedically during the previous 12 months. Legal medicines in this category include methylphenidate (Ritalin), the amphetamine Adderall and modafinil (Provigil). On some campuses, one quarter of students have reported using the drugs. And an informal online reader survey by *Nature* in 2008 showed 20 percent of 1,427 respondents from 60 countries polled about their own use said they had used either methylphenidate, modafinil or beta blockers (the last for stage fright). Overall, a need for improved concentration was the reason cited most frequently. People often manage to acquire the drugs on the Internet or from doctors, who can prescribe medicines approved for one purpose to treat something else (drugmakers, however, cannot legally promote such "off label" uses).

Ingestion of these chemicals will most likely grow along with an aging population and with an increasingly globalized economy. "If you're a 65-year-old living in Boston and your retirement savings have decreased dramatically and you have to stay on the job market and compete with a 23-year-old in Mumbai to stay alert and stay effective, you may feel pressured to turn to these compounds," asserts Zack Lynch, executive director of the Neurotechnology Industry Organization.

The recent push for ethical guidelines, of course, presumes that these drugs are better than placebos and do in fact improve some aspect of cognition, be it attention, memory or "executive function" (planning and abstract reasoning, for instance). Given that assumption, many argue, it behooves ethicists to consider the ramifications of the popularity of these drugs. Such logic led in 2002 to a new academic discipline, neuroethics, meant in part to address the moral and social questions raised by cognition-enhancing drugs and devices (brain implants and the like).

Taking a highly provocative stand, a group of ethicists and neuroscientists published a commentary in *Nature* in 2008 raising the prospect of a shift away from the notion of drugs as a treatment primarily for illness. The article suggested the possibility of making psychostimulants widely available to the able-minded to improve performance in the classroom or the boardroom, provided the drugs are judged to be safe and effective enough for healthy people. Citing research demonstrating the benefits of these drugs on memory and various forms of mental processing, the investi-

FAST FACTS

ENHANCEMENT ETHICS

1. College students and executives ingest stimulant drugs to enhance routine mental performance, although the compounds were never approved for that purpose.
2. Some ethicists and neuroscientists have raised the prospect of making these drugs widely available for enhancement of healthy people who do not suffer from dementia.
3. Questions remain about whether any drug that tinkers with basic mental functioning will be sufficiently safe and effective to be consumed like coffee or tea.

LUCY READING-IKKANDA (*graph and pills*); GETTY IMAGES (*man studying*); LARRY DALE GORDON (*man in office*)

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gators equated pharmaceutical enhancement with "education, good health habits, and information technology—ways that our uniquely innovative species tries to improve itself."

Six months later one of the article's authors, John Harris, a bioethicist at the University of Manchester in England, went further in an opinion piece in the *British Medical Journal*. Harris, at the time an editor of the *Journal of Medical Ethics* and author of the 2007 book *Enhancing Evolution,* noted that if methylphenidate is judged safe enough to be used in children, it should be considered sufficiently innocuous for consumption by adults interested in turbocharging their brains. In a later interview, Harris said he foresaw a gradual loosening of restrictions, and if no safety problems arise, the drug (a controlled substance in the U.S.) could ultimately become an over-the-counter purchase, like aspirin.

These musings have not gone unchallenged. Other researchers and ethicists have questioned whether drugs that modulate mental processes will ever have a safety profile that will justify their being dispensed in the same fashion as a nonprescription painkiller or coffee or tea.

"People say that cognitive enhancement is just like improving vision by wearing glasses," says James Swanson, a researcher at the University of California, Irvine, who was involved with clinical trials for both Adderall and modafinil for ADHD. "I don't think people understand the risks that occur when you have a large number of people accessing these drugs. Some small percentage will likely become addicted, and some people may actually see mental performance decline. That's the reason I'm opposed to their general use." Along these lines, the British Home Office, the interior ministry, has been considering for years whether the potential harm from nonmedical use of enhancers requires new regulations.

Other scientists assert that the debate may be moot because improving smarts might not be possible through any means but the tedious exercise of studying for a calculus exam. Some who have tried to develop drugs to reverse the memory loss of dementia doubt whether enhancement of the healthy is anything but a remote possibility. "I would not worry much about implications of cognitive enhancers in the healthy, because there are no cognitive enhancers to worry about," says Rusiko Bourtchouladze, author of a popular book about the science of memory and a researcher who contributed to the work that led to a Nobel Prize for Eric R. Kandel in 2000. "To talk about cognitive enhancement, it's too, too early, and these drugs may not arrive even in our lifetime. There's too much noise about this."

In this view, the complex mix of chemical signals, enzymes and proteins that collaborate to form a memory creates a self-regulating balance that resists tinkering unless disrupted by disease. The decline in thought processes and sense of identity that comes with dementia might be addressable by compensating for losses of key chemicals and might merit the risk of untoward side effects from drug intervention. But upsetting the fragile stasis in the healthy could produce unintended consequences: as just one example, any improvement in long-term memory (the place where recollections of childhood and last year's vacation re-

THE AUTHOR

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Brain Boosters. Really?

The scientific literature and popular press commonly cite the medicines below—approved for neurological disorders—as having potential to improve mental functioning in unimpaired people. The evidence is decidedly mixed, however, and even if the drugs do prove helpful, their risks may keep the agents from gaining approval by regulators for marketing to healthy individuals.

DRUG	MEDICAL USE	EFFECTIVENESS AS ENHANCER	RISKS
Methylphenidate (Ritalin, Concerta and others) and amphetamines (Adderall and others)	Stimulants used for treatment of attention-deficit hyperactivity disorder (ADHD) and narcolepsy (uncontrollable sleep spells)	Increase cognitive performance on certain tasks under conditions of fatigue; may improve planning and one type of working memory; appear to increase functioning on dull, repetitive tasks	Could worsen performance in a subset of users or on complex tasks; cardiovascular complications and seizures, hallucinations and addiction
Modafinil (Provigil)	Newer-generation stimulant for narcolepsy and excessive sleepiness because of shift work or obstructive sleep apnea	Appears to augment mental focus and better performance on a limited set of cognitive measures, such as recall of long strings of numbers	May have a higher potential for addiction than originally thought; may cause serious skin rashes
Donepezil (Aricept)	Treatment for the cognitive deficits of Alzheimer's disease; increases the neurotransmitter acetylcholine to improve cognition	Might aid in learning or memory, but overall results are equivocal; may take several weeks to work and is not as widely used off-label as the drugs above	Could cause a slight deterioration in cognitive performance in healthy individuals

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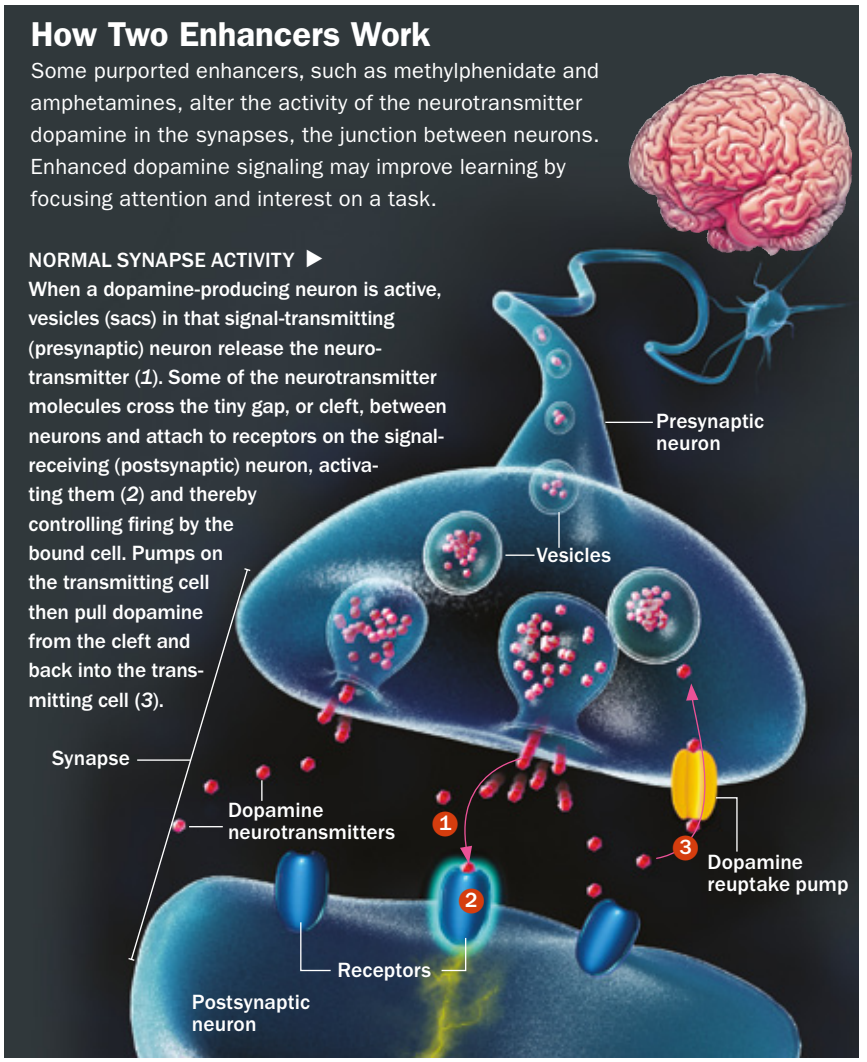
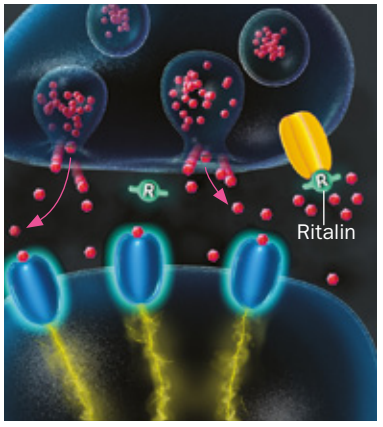
How Two Enhancers Work

Some purported enhancers, such as methylphenidate and amphetamines, alter the activity of the neurotransmitter dopamine in the synapses, the junction between neurons. Enhanced dopamine signaling may improve learning by focusing attention and interest on a task.

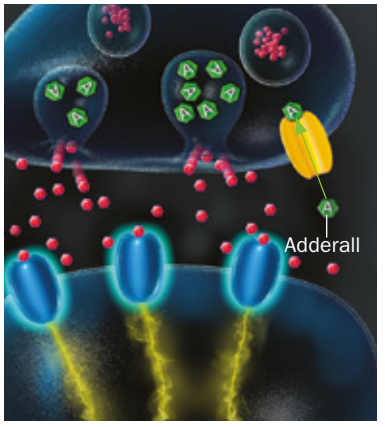

NORMAL SYNAPSE ACTIVITY ▶
When a dopamine-producing neuron is active, vesicles (sacs) in that signal-transmitting (presynaptic) neuron release the neurotransmitter (1). Some of the neurotransmitter molecules cross the tiny gap, or cleft, between neurons and attach to receptors on the signal-receiving (postsynaptic) neuron, activating them (2) and thereby controlling firing by the bound cell. Pumps on the transmitting cell then pull dopamine from the cleft and back into the transmitting cell (3).
Presynaptic neuron
Vesicles
Synapse
Dopamine neurotransmitters
1
2
3
Dopamine reuptake pump
Receptors
Postsynaptic neuron

▼ DRUG-ENHANCED SYNAPSE ACTIVITY

Methylphenidate (Ritalin and Concerta, for instance) blocks the reuptake of dopamine. More dopamine is available to attach to a postsynaptic neuron, which amplifies the strength of the signal transmitted from the presynaptic neuron.



Adderall and other amphetamines enter the presynaptic neuron through the pumping mechanism and cause dopamine to be displaced into the synaptic cleft, increasing the amount of neurotransmitter available to act on the postsynaptic cell.



side) could be countered by diminished capacity for working memory (the mental scratch pad where your brain stores a telephone number temporarily).

Some critics of those who argue over the ethics of neuroenhancement attribute the current flap to what they call "speculative ethics." This tendency also besets nanotechnology and other technological endeavors in which ethicists, scientists and policy makers are diverted by discussions of the social implications of technologies yet to be invented, be they smart pills or nanorobots run amok. "A significant part of the debate on human enhancement … suffers from inflated expectations and technology hype," notes Maartje Schermer of Erasmus University Rotterdam and her colleagues in the journal *Neuroethics*.

A Checkered History

The notion that existing drugs might enhance cognition in the healthy dates back for the better part of a century and has produced ambiguous results. Chemist Gordon Alles introduced amphetamine for medical use in 1929, a synthetic drug chemically similar to the Chinese herb ephedrine. (Alles also devised the drug Ecstasy, another amphetamine.) Various forms were dispensed on both sides during World War II to keep soldiers awake and alert and to bolster courage. The Germans and Japanese ingested methamphetamine, while the British and Americans used Benzedrine, a similar drug to Adderall.

Scientists soon wanted to know whether the perceived benefit in performance was genuine. Psychological assessments by both British and Americans during the 1940s found that users self-rated their performance highly on tests that measured reading speed, multiplication and other factors. But their test scores, in most tasks, were no better than those earned by subjects who ingested caffeine. Performance, in fact, could decline on more complex tasks. "Because of their mood-elevating effects, amphetamines tend to make us feel we are performing especially well, when in fact we are not," says Nicolas

ANDREW SWIFT

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Rasmussen, a historian of science at University of New South Wales in Sydney and author of the book *On Speed* (New York University Press, 2008). "In simplistic lab tests assessing performance on boring tasks, they boost scores by increasing diligence, but that's not the same as taking a law school exam or flying in combat."

Methylphenidate, a close chemical relative of the amphetamines, emerged in 1956 as a supposedly milder and gentler form of stimulant ("the happy medium in psychomotor stimulation," in the words of the drugmaker), but both its biochemical and psychological effects are similar when adjusted for dose. The halcyon era for amphetamines occurred more than 40 years ago. U.S. consumption reached as much as 10 billion pills in the late 1960s before the Food and Drug Administration clamped down and labeled them as controlled substances that required a special prescription. Neuroscientist Michael S. Gazzaniga of the University of California, Santa Barbara, one of the authors of the *Nature* commentary, remembers his father sending him Benzedrine for studying when he was in college in the early 1960s.

In the mid-1990s the growing use of methylphenidate for treatment of ADHD prompted researchers to deploy novel brain-imaging techniques and sophisticated neuropsychological tests to examine effects of the drug in healthy subjects, supplying a baseline for comparison with patients with ADHD and other neuropsychiatric disorders. A 1997 paper in *Psychopharmacology* by Barbara Sahakian, Trevor Robbins and their colleagues at the University of Cambridge showed that methylphenidate improved cognitive performance on several measures (spatial working memory and planning, in particular) in a group of rested, healthy young males but not on others, including attention and verbal fluency. As testing progressed, the volunteers seemed to make more errors in their responses, perhaps because of impulsivity induced by effects of the drug.

The same researchers found little cognitive benefit in healthy elderly males. And in 2005 a group at the University of Florida Medical School at Gainesville could not turn up any cognitive boost from the drug among 20 sleep-deprived medical students. Another impediment to methylphenidate ever being placed alongside NoDoz and other caffeine pills is its potential for causing cardiac arrhythmias and for abuse as a recreational drug. Addiction is rare with normal dosing. But in the 1970s methylphenidate users routinely became addicted after inhaling or injecting the drug that they called "West Coast."

The Always-On Drug

The checkered legacy of amphetamines prompted neuroscientists and physicians to hail the arrival of modafinil as a wakefulness-promoting agent with a seemingly more favorable side effect and abuse profile than the amphetamines. The ability of modafinil (introduced in the U.S. in 1998) to allow people to work long stretches without the need for breaks has turned it into a lifestyle drug for the jet-lagged who attempt to live in four time zones at once.

Jamais Cascio, an associate of the Institute for the Future in Palo Alto, Calif., obtained a prescription for modafinil from his physician after hearing about it from friends who traveled a lot. On trips overseas, he noticed that it made him feel not only more awake but also sharper. "The perceived increased cognitive focus and clarity was very much of a surprise, but it was a very pleasant surprise," says Cascio, who has mentioned the drug in some articles he has written. "My experience was not that I'd become a superbrain. It was more an experience of more easily slipping into a state of cognitive flow, a state of being able to work without distraction."

Testing has confirmed some of Cascio's impressions. In 2003 Sahakian and Robbins found that 60 rested, healthy male volunteers did better on a few neuropsychological measures, such as recall of numerical sequences, but results were unchanged on others. Investigators elsewhere have also found benefits for the drug, although, as Cascio noted, it will not make a dunce into a genius.

A Warrior's Little Helper

The notion that a pill could improve mental and physical performance in healthy people gained credence during World War II. Both sides in the conflict consumed millions of amphetamines, such as these "wakey wakey" pills distributed by a British Royal Air Force medical officer to a member of a bomber flight crew.

COURTESY OF COMMONWEALTH AIR TRAINING PLAN MUSEUM

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None of these studies, moreover, has tested effects on cognition over extended periods.

Unregulated availability of either modafinil or methylphenidate also remains unlikely because the drugs tend to affect individuals in different ways. Users with lower IQs appear to derive a large performance boost from modafinil, whereas those with more innate ability show little or no benefit. With methylphenidate, those having poor working memory improved when tested; those having a naturally higher memory capacity showed much smaller benefits.

As with amphetamines, modafinil did not emerge from a basic understanding of the underlying biology of how the brain works. Present research shows, however, that the drug seems to involve multiple neurotransmitters, the chemicals that trigger the firing of specific clusters of neurons. The drug's exact mechanism remains to be elucidated. But recently Nora D. Volkow, director of the National Institute on Drug Abuse, and her colleagues discovered that one of those neurotransmitters is dopamine, the same chemical that is boosted by amphetamines and that imbues those drugs with their addiction potential. "It appears that methylphenidate and modafinil are very similar in what they're doing to the dopamine system in the brain, contrary to what was believed," says Volkow, although she adds that it is not practical to smoke or ingest modafinil to produce a strong high, so the possibility of abuse is lower. Another roadblock to wider use appeared in 2006, when the FDA rejected the drug as a treatment for ADHD in children because of reports about serious skin rashes.

Repackaging old attention-boosting drugs as cognitive enhancers for students, executives and software programmers may produce only marginal benefits over consuming a double espresso. The question of what exactly is an enhancer has, at times, prompted professionals in the field to consider standards that any drug should meet to be classified as a cognitive booster. Ultimately enhancement drugs may come from another sphere of research. Insights into how we translate a baby's image or a friend's name into lasting memories has laid the groundwork for new drugs specifically designed to achieve better functioning in people with Alzheimer's or other dementias.

Optimism about a new generation of pharmaceuticals derives in part from advances in basic research into the biochemical processes underlying memory formation. More than 30 types of gene-altered mice have demonstrated the ability to both acquire information and store it in long-term memory better than the average mouse. "This is the first time in the history of neuroscience that we have the backbone of the molecular and cellular biology of memory," says Alcino J. Silva, a neurobiologist at the University of California, Los Angeles. "What this means for society is that for the first time we can use it to start changing how we learn and remember."

But truly effective memory drugs are probably a long way off, in part because of the scientific challenges. Most of the 200 gene mutations introduced into mice by researchers worldwide caused deficits. Silva remembers one mouse in his laboratory that illustrated the possible trade-offs that researchers will confront during development of a cognitive enhancer. The animals learned faster than normal, unaltered mice but were unable to complete an elaborate puzzle administered by the investigators. "If you taught them something simple, they acquired it fast, but for anything more complicated, they couldn't acquire it," Silva says. He estimates that it may take decades before drugs from this research are routinely used.

The logistical challenges are daunting as well. Several of the first companies to enter the fray, including ones founded by leading academics, have faltered. In 2004 *Science* magazine cited four new firms—Sention, Cortex Pharmaceuticals, Memory Pharmaceuticals and Helicon Therapeutics—as exemplars of a trend. Sention went out of business. Cortex merged with Pier Pharmaceuticals in 2012 and now focuses entirely on treatments for breathing disorders. In 2008 Hoffmann–La Roche purchased at a penny-stock price (less than $1) Memory, co-founded by Nobelist Kandel, after it had experienced layoffs and a number of failed clinical trials. The research program of Helicon—the company merged with Dart NeuroScience in 2012—has survived because of the largesse of billionaire Kenneth Dart, the Styrofoam cup magnate, who was enticed by the prospect of memory drugs. The company has been developing a drug that would modulate a pathway related to glutamate, a neurotransmitter that triggers an intricate cellular signaling path related to the formation of long-term memories [*see box on opposite page*].

Before the merger, Helicon received more than $100 million in funding but failed to reach late-stage clinical trials for any of its drug candidates. "The way I like to explain this to audiences when I give talks is that when Helicon was formed I thought that I was making memory enhancers for my parents and I had no gray hair," says Tim Tully, Dart's executive vice president and chief scientific officer, who co-founded Helicon when he was at Cold Spring Harbor Laboratory. "They're now dead, I'm fully gray, and I'm fully cognizant of the fact that this is a race for me not them."

Tully, 60, adds that he does not foresee his creations ever becoming the next Viagra or Prozac. "What the media loves to totally ignore is the side-effect potential and jump right to the wild speculation of this as a lifestyle drug," he says. "And I think it's just missing the mark. The reality is that if you've got a debilitating form of memory impairment these drugs may be helpful, but they're probably going to be too dangerous for anyone else."

Despite these cautionary tales, drugmakers continue trying to develop

LUCY READING-IKKANDA (*pills*)

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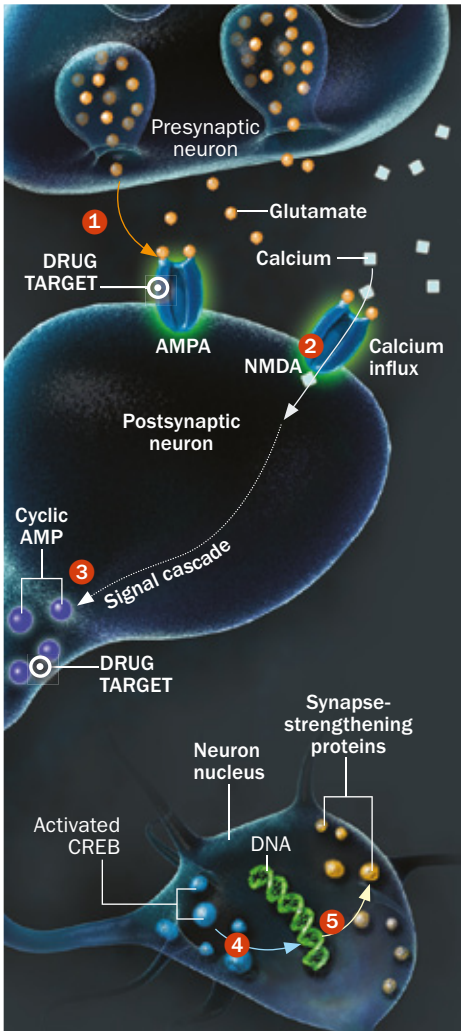

Drugs to Remember

Researchers have labored, in one instance for almost 25 years, on drugs that enhance cognition by acting on molecules involved in long-term memory.

Neuroscientists postulate that long-term memory involves attachment of the neurotransmitter glutamate to two types of receptors on recipient neurons. After the AMPA receptor is bound (*1*), it leads the other bound receptor—the NMDA type—to open a channel, allowing an influx of calcium (*2*). Calcium sets off a train of signaling that activates a molecule, cyclic AMP (*3*), which, in turn, switches on other molecules that migrate to the cell's nucleus and turn on the CREB protein (*4*). CREB acts on DNA in a way that triggers synthesis of proteins that then move back to the synapse and strengthen the signaling connection between the glutamate-emitting and glutamate-receiving neurons (*5*). Drugs that make this process more efficient—either by enhancing signaling through AMPA receptors or by keeping cyclic AMP working longer—have gone through a few clinical trials.

cognitive enhancers for Alzheimer's and other dementias. Among the compounds under consideration are ones that alter the effects of neurotransmitters other than glutamate—including receptors switched on by the nicotine in tobacco (though not the one linked to addiction). One of the reasons that people smoke is because nicotine helps to sharpen attention.

Lessons learned from drugs developed for dementia could lead to agents that ease the milder cognitive problems associated with normal aging, assuming these compounds do not arrive burdened with intolerable side effects. If sufficiently benign, these pills could find their way into college dorms or executive suites. "Within the pharmaceutical field, people recognize that a successful cognitive enhancer could be the best-selling pharmaceutical of all time," says Peter B. Reiner, a professor of neuroethics at the University of British Columbia.

Near to Market

As scientifically satisfying as it would be for researchers to discover cognition-enhancing drugs through detailing the molecular processes that underlie cognition, the first new agents to reach the market for dementia and other cognitive disorders may not spring from deep insight into neural functioning. They may come from the serendipitous discovery that some compound approved for another purpose has effects on cognition.

For instance, one drug candidate, which ultimately failed for the cognitive dysfunctions of Alzheimer's, was developed in Russia as an antihistamine for hay fever and was later found to have antidementia properties. The potentially huge market has led some companies to take unorthodox routes to market, revisiting a failed drug or one that did not complete clinical trials and selling it as a dietary supplement or as a less stringently regulated "medical food."

Similarly, new medicines may arrive because regulatory agencies approve a broadening of allowed uses for a drug already known to influence cognition. Cephalon, maker of modafinil, took this route, obtaining FDA permission to market the substance for shift workers, who compose a much larger group than the narcoleptics (who suffer from uncontrolled sleep episodes) for whom it was originally approved. (Cephalon also paid nearly $444 million to two states and the federal government for promoting three drugs, including modafinil, for unapproved uses.) The impulse to improve cognition—whether to intensify mental focus or to help recall a friend's phone number—may prove so compelling to both drugmakers and consumers that it may overshadow the inevitable risks of toying with the neural circuitry that imbues us with our basic sense of self. M

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ANDREW SWIFT

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WHERE ARE ALL THE FEMALE GENIUSES?

WOMEN TEND TO CHOOSE WORK-LIFE BALANCE RATHER THAN THE PURSUIT OF EMINENCE—ALTHOUGH THE CHOICE IS NOT ENTIRELY FREELY MADE

BY SANDRA UPSON AND LAUREN F. FRIEDMAN

Try this simple thought experiment. Name 10 female geniuses from any period in history. Odds are you ran out of names pretty quickly. The message is clear: something is rotten in the state of genius.

Besting most of one's species is an accident of circumstance. The sequences of DNA nucleotides, arranged *just so* to impart intelligence, curiosity and passion, are part of that fluke event. More serendipitous still are the conditions needed for a person to devote decades to an idea or calling, deaf and blind to the distractions bound up in being human.

That implausible scenario comes into sharp relief in the scarcity of female geniuses. The absence of women reveals the unequivocal role of culture and opportunity in the flourishing of brilliance. For centuries doubts about women's abilities, combined with social customs, limited the so-called fairer sex to household concerns. In the developed world today women's access to education and resources is essentially on a par with that of men. With the barriers to opportunity crumbling, different cultural and social forces explain why women still struggle to reach the very top of their

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fields. "As much as we've been able to open doors, there are huge structural differences in how men and women live out their lives," says psychologist Jacquelynne Eccles of the University of Michigan.

Gifted women face a choice: they can pursue their interests wholeheartedly, or, in line with cultural imperatives, they can split their time and serve as the anchors of their families. The good news is that for those in whom the fires burn brightest, a choice exists—albeit one riddled with compromises. Attaining eminence will never be easy, but fixing the social inequity that still remains should lessen the trade-offs it demands of women today.

CARO BONINK *Redux Pictures*

Few women dominate the chess world. A 2009 analysis offered this explanation: many more men play chess, so men are more likely to excel. Then one might ask: Why don't more women play chess?

Beyond Biology

Francis Galton, the first person to study the hereditary basis of eminence, argued that a gifted man would achieve greatness as long as he "had no pressing calls on his attention, no domestic sorrows, anxieties and petty cares … no constant professional toil for the maintenance of a large family." For men at any time in history this condition is rare—for women, nearly nonexistent.

A woman was expected to be a well-mannered complement to her husband, able to soothe his cares and those of their children. She was not someone who would hole up in an office or studio for hours on end. The few women who bucked the trend did so covertly. The Brontë sisters, for example, published their novels under masculine names. Linda Nochlin, a feminist art historian, noted that until the 1900s women artists were denied many opportunities to develop their craft that men took for granted, including the freedom to paint nude models, join art academies and network with patrons. These closed doors doomed women to obscurity.

Mental or physical frailty was also commonly invoked to discourage women from seeking higher education or public recognition for their work. Those debates are only now being put to rest. More women now graduate from college and enter medical school than men, and more female athletes qualified for U.S. Olympic teams in 2012 than men.

Psychologist Lewis Terman, who in 1921 began an ambitious program of intelligence testing, reported that the three highest IQ scores in his first survey of gifted children belonged to girls. More recent work has established that, in aggregate, women and men perform about the same on intelligence tests.

A 2008 meta-analysis of creativity research reached a similar conclusion. Psychologists John Baer of Rider University and James C. Kaufman, now at the University of Connecticut, reviewed 78 studies of men and women at various ages and found that although some studies showed one gender scor-

FAST FACTS

UNDER PRESSURE

1. For most of history women in the Western world were denied opportunities to seek higher education and develop their talents.
2. The dearth of women at the top of their fields is now often the result of compromises made for the sake of family, rather than differences in ability.
3. Women who seek eminence face difficult choices regarding when to invest in their careers versus their personal lives. More cultural and institutional support for women could dispel the lingering gender disparities.

THE AUTHORS

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ing higher than the other on measures of creativity, these findings were almost always counterbalanced by experiments showing the opposite effect.

Lonely at the Top

Baer and Kaufman did, however, find a large gap in the productivity of creative men and women. Explaining the differences in creative output is now the "most significant" question, they conclude. The data suggest that early in their careers, women are pulling out of the race to eminence.

Lingering gender bias, often unconscious, may account for some of the attrition. The advent of blind auditions for orchestras, beginning in the 1970s, is one famous example of discrimination and its abatement: the odds of a female musician advancing through the early rounds of a tryout increased by 50 percent after orchestras introduced screens to conceal applicants' identities. Skewed ratios still show up in countless domains, however. Recent reports have found, for instance, that women write one fifth of the editorials in traditional media outlets and about one third of the articles in top-tier magazines and literary journals. Without data on the numbers of submissions by gender, however, the causes of disparity remain occluded.

Cornell University psychologists Wendy M. Williams and Stephen J. Ceci (who is a member of *Scientific American Mind*'s board of advisers) investigated this question in a 2011 review of studies on gender discrimination in science and engineering. They concluded that the low numbers of women in these fields exist not because of unfair practices in the awarding of grants, job offers or publication in prestigious journals. When they compared only people with similar accomplishments and resources, men and women were equally likely to receive those accolades. Instead they found the gap stems from preferences relating to family and work-life balance. Women were more likely to accept less desirable posts, which offer less time for research, often to accommodate raising a child or tending to an aging parent.

A 2009 survey of more than 8,000 doctoral students in the University of California schools bolsters this observation. Half the female respondents were "very concerned" that a career in academia might not be family-friendly, compared with a third of men. Considerably more women than men described their professional activities as being too time-consuming, incompatible with children or a partner, or geographically problematic. Fears of conflicting priorities are not unfounded—the respondents who were also mothers reported logging more than 100 hours a week on academic work, caregiving and housework; fathers clocked around 90 hours.

To further pinch ambitious women in academia, the years during which women must receive their degrees, land a job and work toward tenure (received at an average age of 39) coincide perfectly with the prime years for having children. "When we put all the studies together, what we find is that marriage and childbirth are the most predictive variables in terms of the attainment of eminence," says psychologist Barbara Alane Kerr of the University of Kansas.

Divided Focus

Choices made for family reasons are intensely personal and often admirable—but they are not conducive to genius-level accomplishment. Rising above the rest demands single-minded devotion to one's craft. "Females still are less likely to aspire to that way of life," Eccles says. "It means giving up just about everything else and having a supportive network so you *can* give up everything else."

For women in academia, offering child care assistance and more options for slowing down the tenure process could absorb some of the temblors knocking women off the path to greatness, as a 2004 report from the Government Accountability Office advised. More broadly, Kerr suggests that women recognize the importance of timing in their major life decisions and seek parity in their relationships within the family and with colleagues. Only when gender assumptions about household responsibilities are finally washed out of the fabric of society can women face equal odds as men.

The lack of diversity in the annals of great achievement both admonishes and enlightens us about the nature of true genius. If creative potential is a new shoot poking out of the soil, successful growth depends on whether life sends in the lawnmowers or offers protective cover. As Anne Fausto-Sterling, a biologist and gender expert at Brown University, puts it, "what's really important is how people of high ability are nurtured, sustained and given the opportunity to fulfill their abilities." Genius is still the product of lucky coincidences, but society need not load the dice. M

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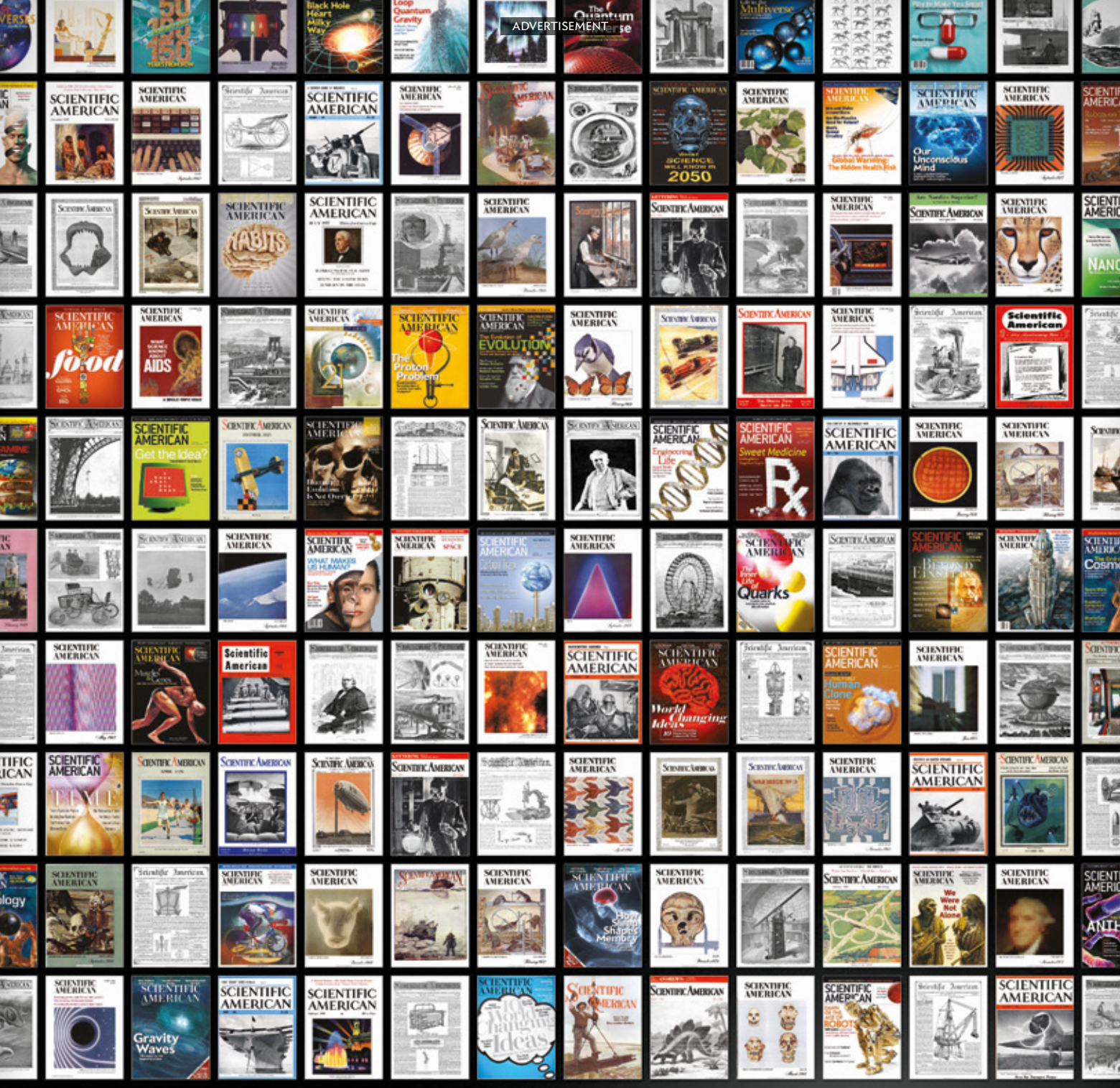

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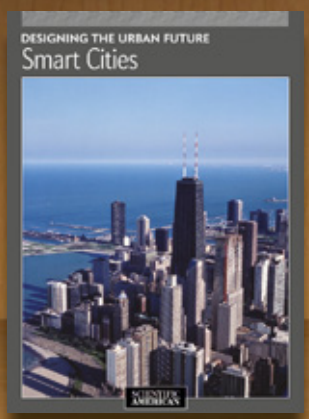

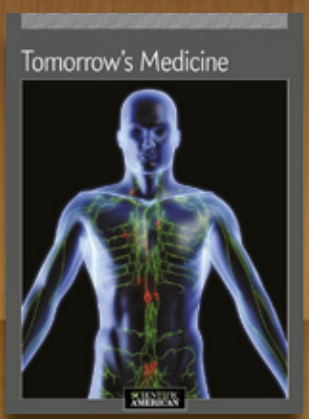

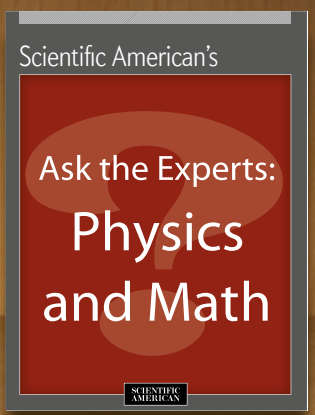

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